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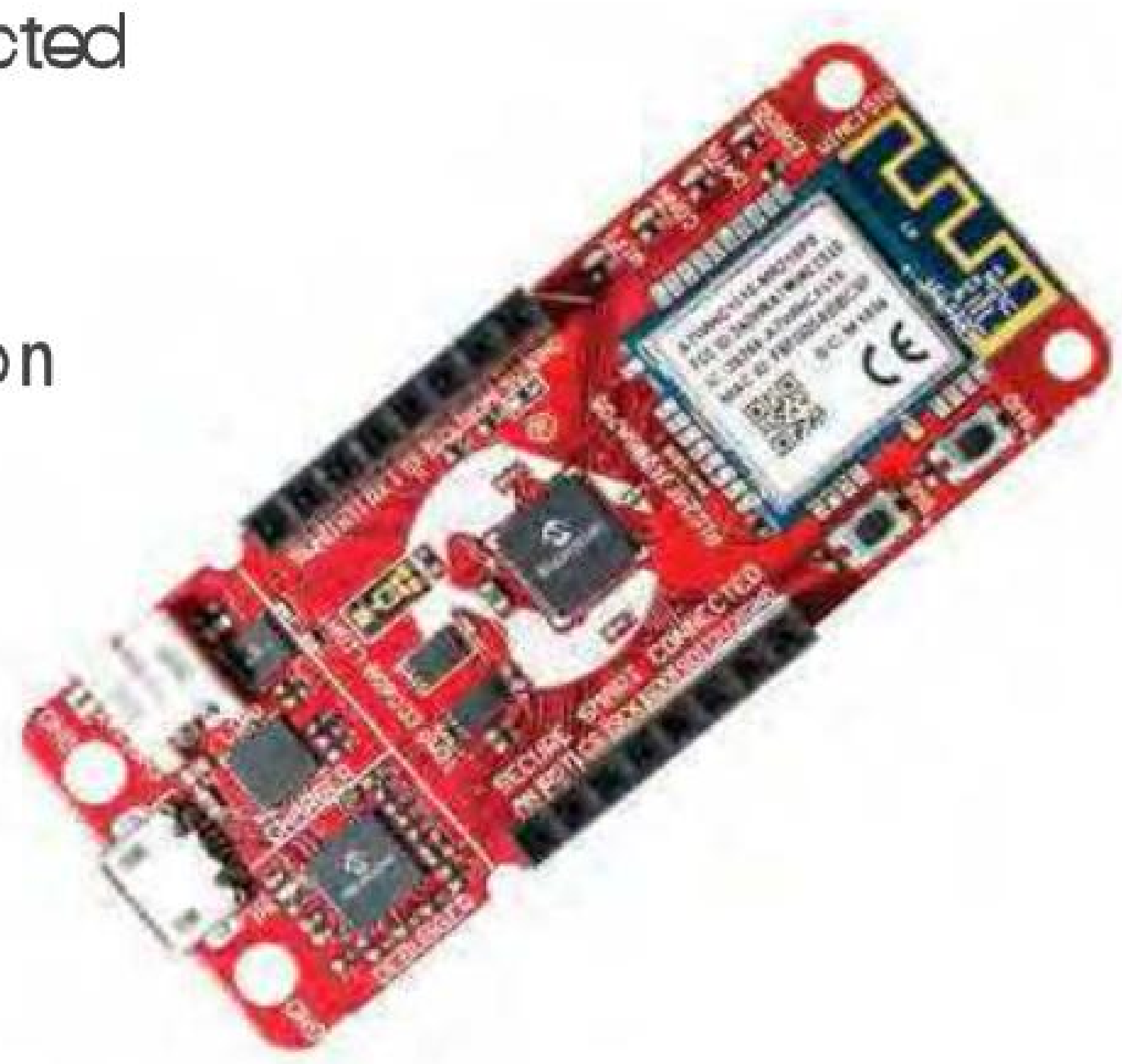

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Practical Electronics

Volume 49. No. 11
November 2020
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by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

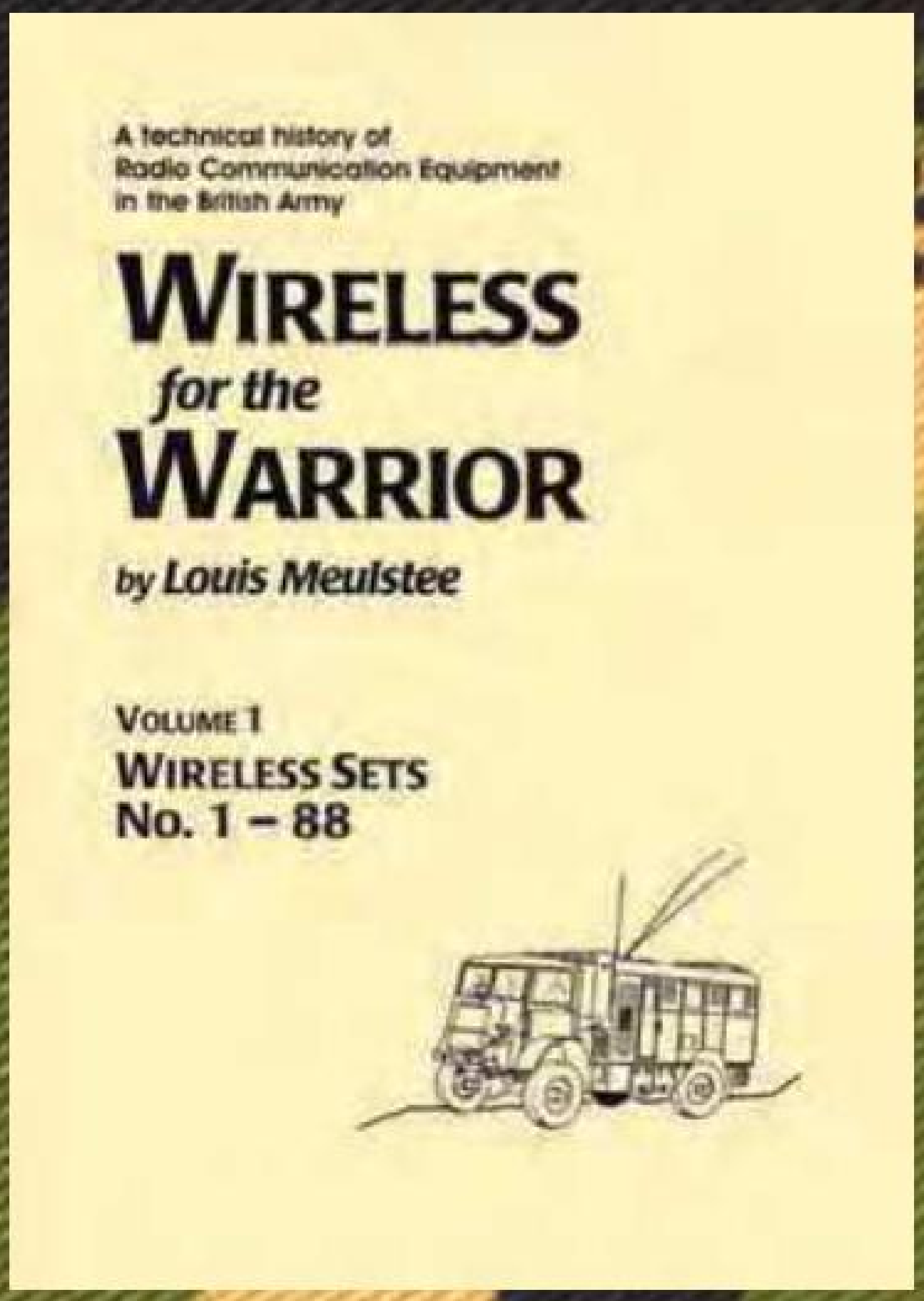
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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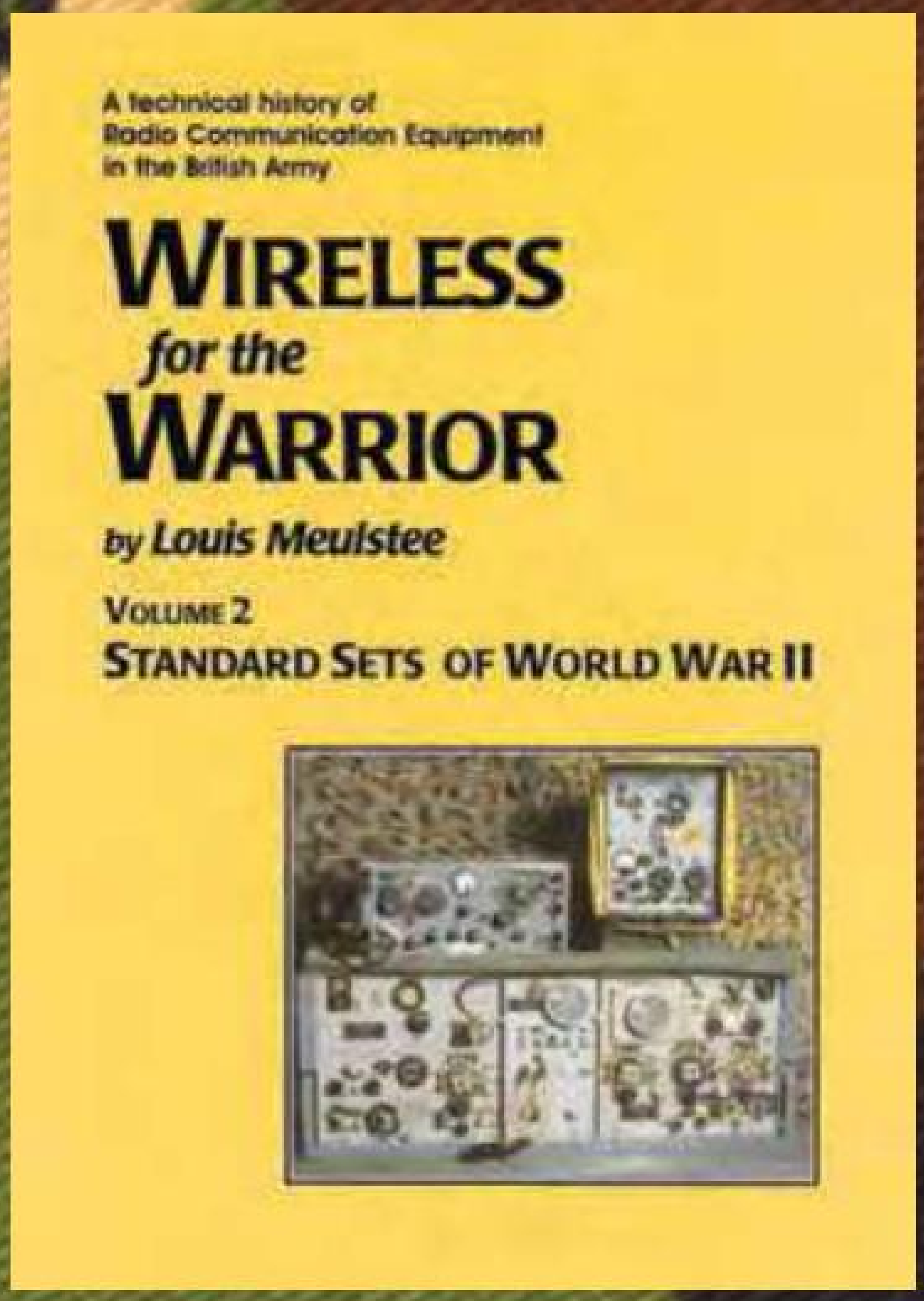

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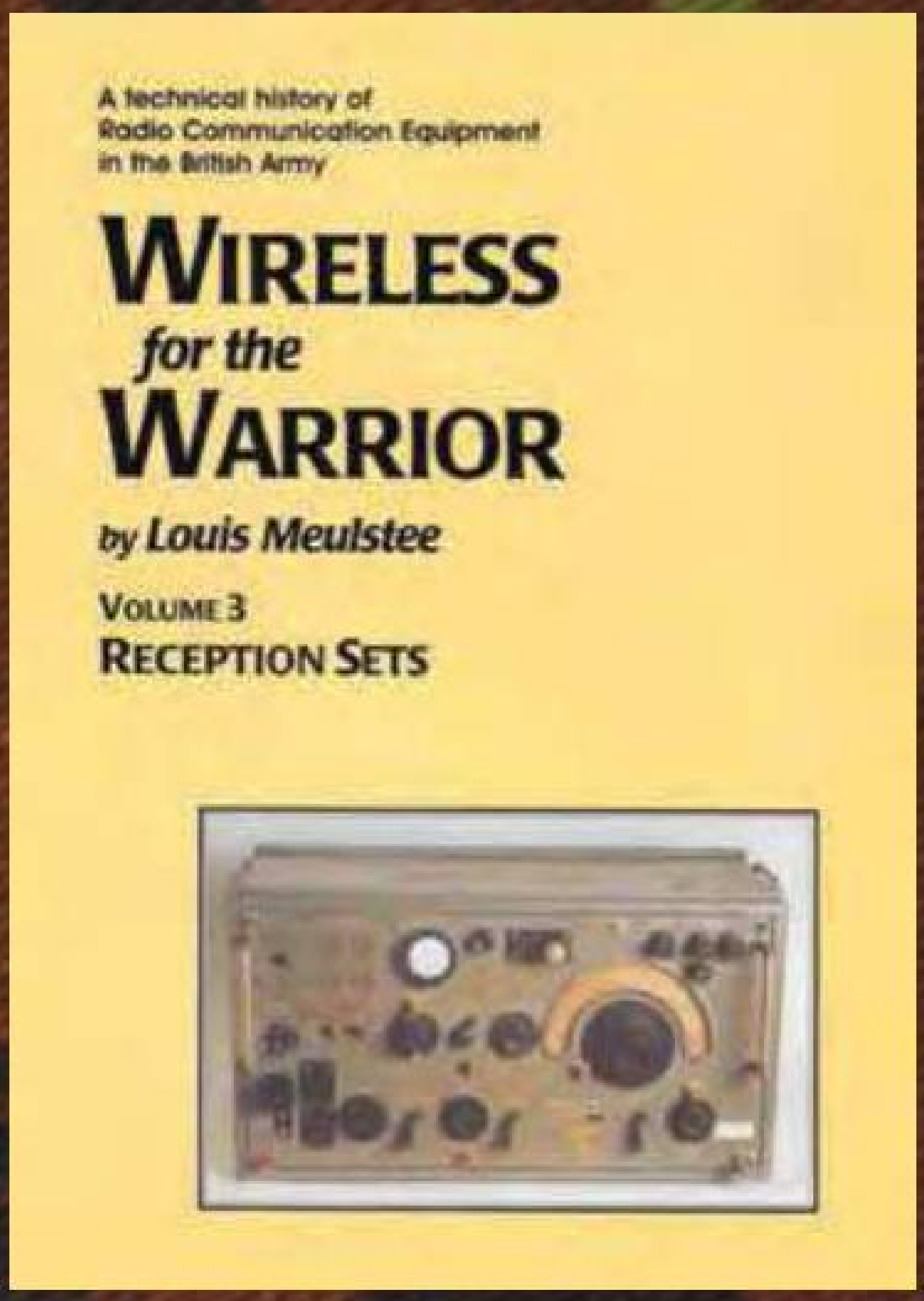

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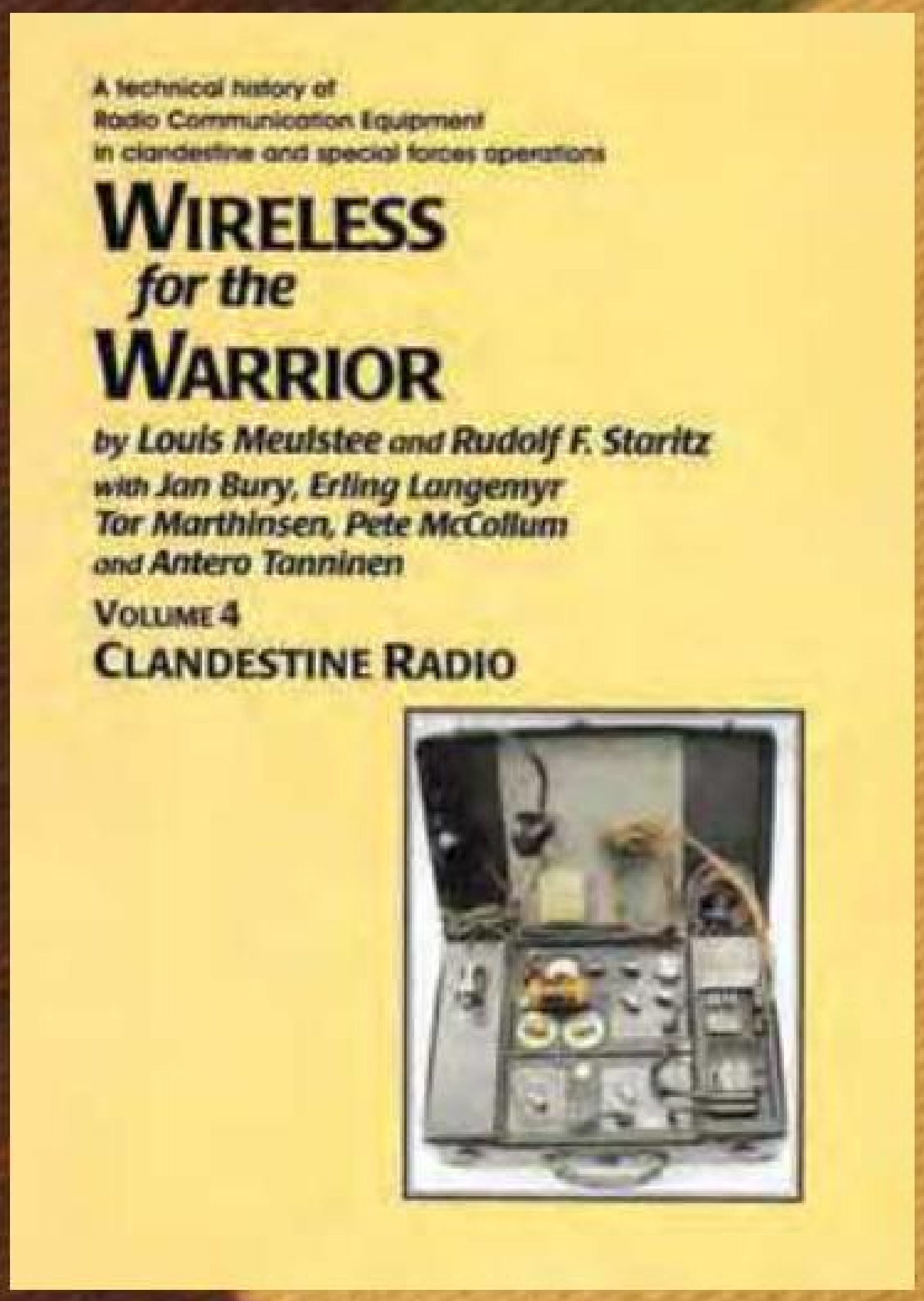

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in clandestine and special forces operations

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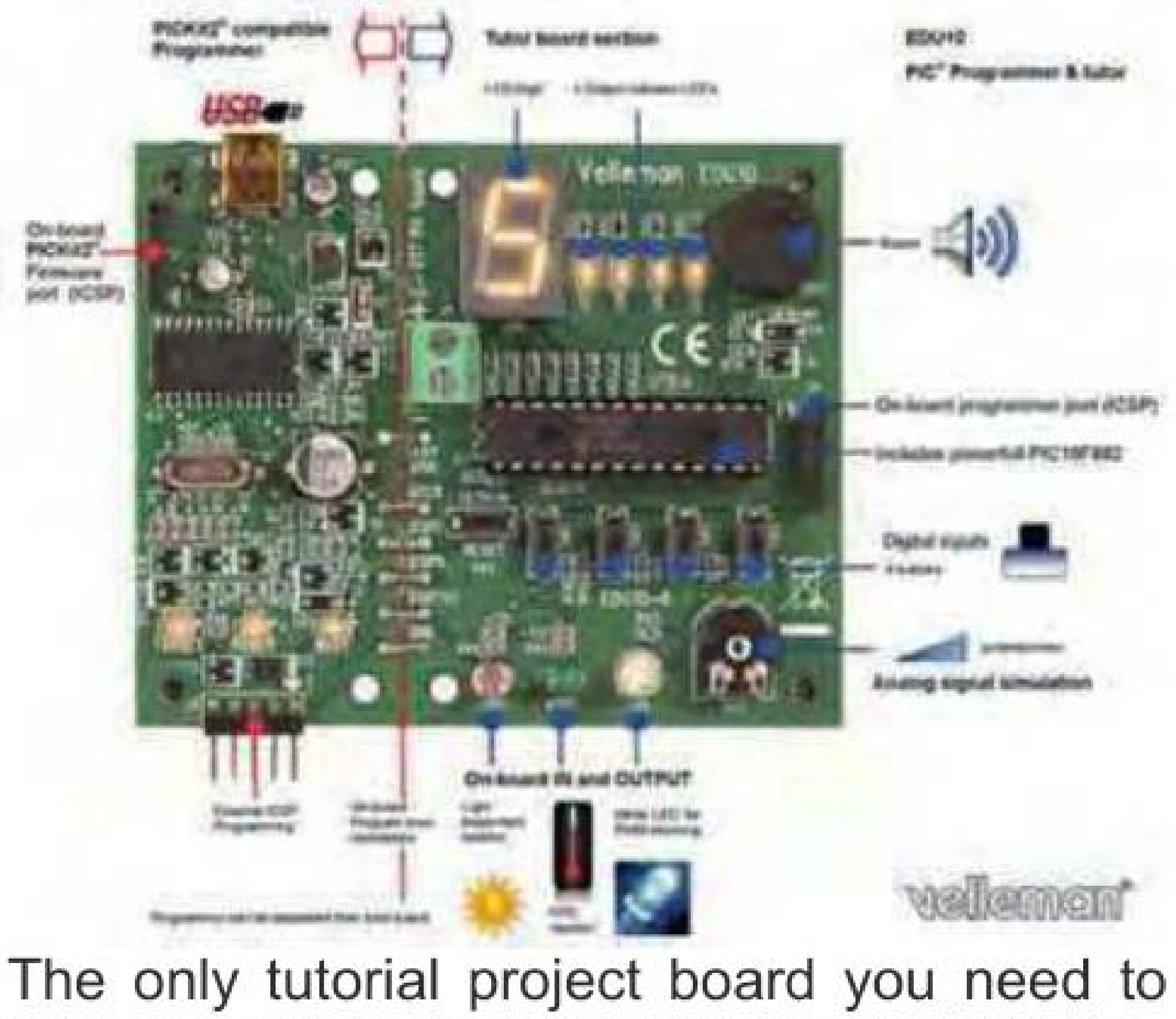

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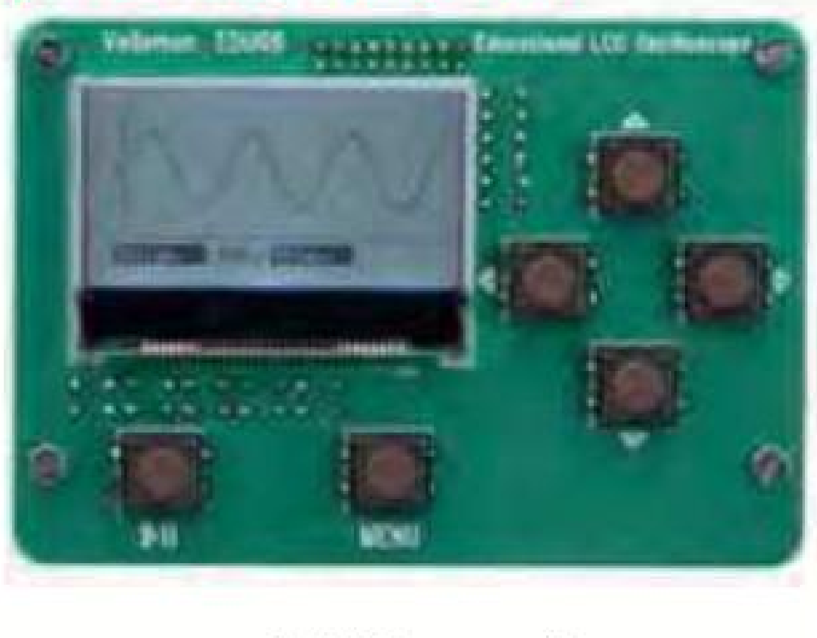

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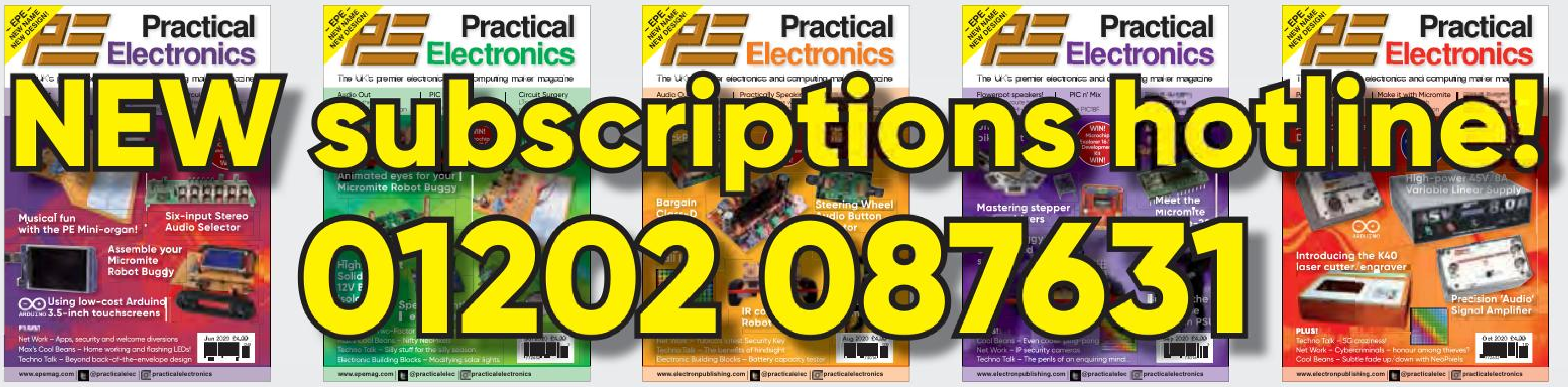

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Battery Day is here

When I started my career as a research engineer in the late 1980s, I had the good fortune to work for an innovative automotive component manufacturer. The projects I worked on tended not to be car related, but more ‘Blue Skies’ research that looked far ahead at engineering which was not yet ready for commercialisation, but which would one day become useful. Despite this, the company did source a lot of publications and journals that were car related, and I remember reading an article that predicted electronics would make up over 20% of the cost of a new car within a couple of decades. At the time, it struck me as absurd – how could an FM radio and a basic ignition system cost so much? What else was there to compete with all that precision mechanical engineering?

Well, if anything, it was an underestimate. As I write, yesterday (22 September) was ‘Battery Day’, according to Elon Musk, the CEO of upstart electric vehicle manufacturer, Tesla. The oddly eccentric, but undoubtedly brilliant Musk claims Tesla have the technology to cut battery costs by more than 50 percent and nearly double the distance their vehicles can travel, setting the stage for the company to make a $25,000 (£20,000) electric vehicle in around three years.

We have certainly passed one tipping point – the lifetime cost of buying/running a midrange electric car is now on a par with a petrol-engine version. If this happens at the cheaper end of the car market then the take-off of battery/electronics-based transport will be extraordinarily rapid. Charging times need to improve and it’s important that we don’t shift the environmental burden to the electricity generators – burning coal to run ‘green’ cars would be the height of folly. Nevertheless, this is an exciting announcement, and although it certainly won’t solve all our transport-related climate-change challenges, Battery Day could signal a big step in the right direction.

Is it too early to mention Christmas?

It happens every year in early September; I go to my local supermarket for a spot of food shopping and I’m faced with the first of what becomes many shelves of green and red tinsel, pointless ‘festive’ trinkets and a not-so-subtle reminder to start thinking about Christmas. I tend to mutter under my breath – ‘already? really? – it’s still (just) summer!’ – and then sigh with the grim resignation that we’re racing towards the end of another year – how do they pass so quickly?

I mention this simply because we have our own little helping of early Christmas ‘cheer’ this month – our *LED Christmas Tree* project. My excuse for this premature Xmas item is first that you will read this in October (so not as awful as September) and second – more reasonably – if you want to build a large version of this project then it is probably worth starting early. If you do decide to build this rather splendid item then don’t miss the special offer for the relevant PCB(s) on page 22. In the meantime, I hope you have a very enjoyable October and November!

Keep well everyone

Matt Pulzer

Publisher

The Fox Report

Barry Fox's technology column

Choosing your monitor – curved or flat?

Remember the curved screen craze of the early 2010s? On a whim and prayer Korean companies Samsung and LG decided that TV screens should wrap around the viewer. Other companies felt they had to follow.

Turan Erdogan, CEO of Vestel, the Turkish electronics giant that manufactures just about anything for numerous household name brands (and no relation to Turkish President Recep Erdogan) said at the time: 'I have spent my life trying to make TV screens perfectly flat, and now I have to curve them.'

Predictably, curvy TV fell by the wayside. The screens weren't big enough, like cinema screens, to wrap round the viewer. Curving wasn't good for family viewing, either. It was 3D all over again.

But now there is a new, real use for curved screens – as computer monitors.

Largely because curving TV screens got a bad name, curving monitors is not being heavily promoted. But I'll argue, after trying one, that a curved computer monitor is a good and useful thing – especially as more people are working from home in a cramped space.

I tried a Philips 241E monitor, with 1920×1080 resolution and specified visible diagonal screen size of 59.9 cm (23.6-inch). The screen curve is only a modest 3cm or so deep, but this is enough to reduce the desk footprint to a measured width of around 53.5 cm (21-inch). So, the slight curve saves several inches of footprint space.

The curved Philips 241E computer monitor 59.9 cm (23.6") 1920 x 1080 pixels Full HD.

The space reduction is not dramatic, which is why the curve does not noticeably affect the shape of displayed content. But it can make the difference between safely squeezing a reasonably wide monitor on a small desk, and having it spill unstably over the sides.

I doubt this is what Samsung and LG had in mind when they tried to foist curved TVs on us, but it's a happy spin-off.

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Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low cost computer that has taken the education and computing world by storm.

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Mike & Richard Tooley

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Techno Talk

Mark Nelson

If we're to eliminate fossil fuels from energy generation, we'll need to exploit a huge range of non-depletable sources of energy. Techniques involving wind, water and solar power are becoming mature sciences, but new 'green' procedures continue to emerge. Read here about electronic house bricks, solar panels that are radically cheaper and devices that relish shadows as much as they enjoy sunlight.

Do you remember the first Motorola 'Brick' mobile phone? It was the ultimate status symbol back in 1985, when cellphones were launched in the UK by BT Cellnet and Racal Vodafone. Its price tag in those days was around £1,000 (£3,000 in today's money) and its 'Brick' nickname came from its size and weight (28oz, 0.8kg), which meant you needed a briefcase to lug it around.

The battery inside the Brick phone was a NiCad device that allowed just 30 minutes of talk time, which compares rather poorly with a new-style brick 'battery' developed at Washington University in St Louis, USA by assistant professor of chemistry Julio D'Arcy. Actually, his development is not a battery but rather a supercapacitor that is also a brick – a real brick.

Conductive fibres

Supercapacitors, you will recall, are electrical energy storage devices that can charge and discharge large amounts of power rapidly. Their form factors vary widely, with large, boxy ones used industrially and small, circular ones appearing in consumer electronics. Washington University chose a radically different approach and made their supercaps in the form of red bricks.

'Our method works with regular brick or recycled bricks, and we make our own bricks as well,' says Julio D'Arcy. 'As a matter of fact, the work that we have published in *Nature Communications* stems from bricks that we bought at Home Depot right here in Brentwood (Missouri); each brick cost 65 cents.'

The bricks must be red, he continues, because the red pigment in them (iron oxide) is essential for triggering the polymerisation reaction that takes place in conductive nanofibers that penetrate the inner porous network of specially modified bricks. 'The polymer coating remains trapped in the brick and serves as an ion sponge that stores and conducts electricity,' he explains. The team's calculations suggest that walls made of these energy-storing bricks could hold a substantial amount of energy.

'Our coated bricks are ideal building blocks that can provide power to emergency lighting,' explains D'Arcy. 'We envision that this could be a reality when you connect our bricks with solar cells and place 50 bricks in close proximity to the load. These 50 bricks could power emergency LED lighting for five hours. Advantageously, a brick wall serving as a supercapacitor can be recharged withinin an hour, hundreds of thousands of times.' Also, with an eye on the smart, connected future of buildings he notes that, 'Using a couple of bricks, microelectronics sensors would be easily powered.'

Cheaper, greener solar panels

Meanwhile, over at Cornell University in New York, imaginative thinking has come up with a new type of solar panel that offers an energy payback on investment in just four months. This is a four-times improvement on the silicon solar cells currently in production. The new technique uses calcium titanium oxide, better known as 'perovskite', which results in a less energy-intensive manufacturing process and is responsible for a much smaller carbon footprint.

Fenqi You, professor in energy systems engineering at Cornell, sums up: 'Perovskite cells are promising, with a great potential to become cheaper, more energy-efficient, scalable and longer lasting. Solar energy's future needs to be sustainable.'

Shadow cells generate power too

You don't need a brain the size of a planet to figure out that solar cells work best in bright daylight, which is bad news for urban areas and other locations that are not bathed in lovely sunlight. Now, researchers from the National University of Singapore have created a clever device called a shadow-effect energy generator (SEG), which generates electricity by making use of the contrast in illumination between lit and shadowed areas. The university asserts that this novel concept opens up new approaches in generating green energy under indoor lighting conditions to power electronics.

Says research team leader, assistant professor Tan Swee Ching, 'This novel concept of harvesting energy in the presence of shadows is unprecedented. In conventional photovoltaic or optoelectronic applications where a steady source of light is used to power devices, the presence of shadows is undesirable, since it degrades the performance of devices. Our work capitalises on the illumination contrast caused by shadows, which induces a voltage difference between the shadow and illuminated sections, resulting in an electric current. The ideal environment for use would be cities, with constantly shifting levels of light and shade throughout the day from clusters of tall buildings and the sun's changing position in the sky.'

Lower cost

The team hopes that its shadow generator can be fabricated at a lower cost compared to commercial silicon solar cells. It comprises a set of SEG cells arranged on a flexible and transparent plastic film, with each SEG cell formed of a thin film of gold deposited on a silicon wafer. This sounds fine, but how does it work?

Team co-leader professor Andrew Wee explains, 'When the whole SEG cell is under illumination or in shadow, the amount of electricity generated is very low or none at all. When a part of the SEG cell is illuminated, a significant electrical output is detected. We also found that the optimum surface area for electricity generation is when half of the SEG cell is illuminated and the other half is in shadow, as this gives enough area for charge generation and collection respectively.'

In indoor lighting conditions with shifting shadows, the harvested energy is sufficient to power a digital watch (1.2V). In the next phase of research, the team will experiment with materials other than gold, to reduce the cost of the SEG.

Win a Microchip PIC24FJ256GA7 Curiosity Development Board

Practical Electronics is offering its readers the chance to win a Microchip PIC24FJ256GA7 Curiosity Development Board (DM240016) – and even if you don't win, receive a 20%-off voucher, plus free shipping for one of these products.

The PIC24FJ256GA7 Curiosity Development Board is a cost-effective, fully integrated 16-bit development platform targeted at first-time users, makers and those seeking a feature-rich rapid prototyping board. Designed from the ground-up to take full advantage of Microchip's MPLAB X IDE and MPLAB Xpress Cloud-based IDE, the board includes an integrated programmer/debugger and requires no additional hardware, making it a perfect starting point to explore the latest low-cost and eXtreme Low Power (XLP) 16-bit PIC24FJ256GA705 family of Microcontrollers.

The PIC24FJ256GA7 Curiosity Board enables easy and faster adoption of the low-cost XLP 16-bit PIC24FJ256GA705 family of microcontrollers. The PIC24FJ256GA705 microcontroller, featuring up to 256KB of ECC flash and 16KB of RAM, is ideally suited for low-power general-purpose applications.

The layout and external connections of the PIC24FJ256GA7 Curiosity Board offer unparalleled access to Core Independent Peripherals (CIPs) such as CLC, MCCP and DMA. These CIPs enable the user to integrate various system functions onto a single MCU, simplifying the design and keeping system power consumption and BOM cost low.

The PIC24FJ256GA7 Curiosity Development Board offers seamless integration with the Microchip software tool chain, including the MPLAB Xpress Cloud-based IDE, XC16 compiler and MPLAB Code Configurator for easy set-up and prototyping.

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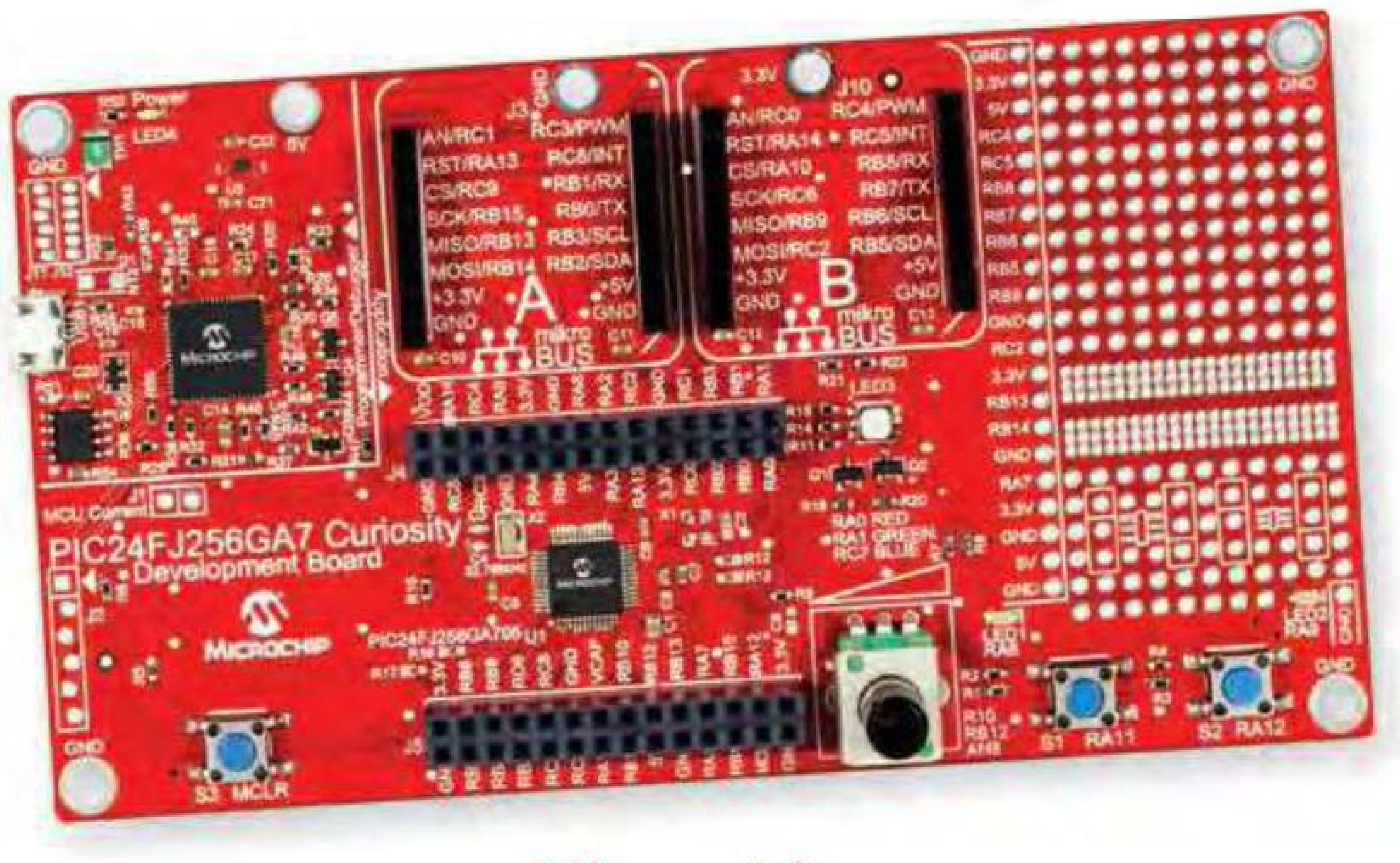

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The closing date for this offer is 31 October 2020.

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He won a Microchip PIC-BLE Development Board

Net Work

Alan Winstanley

This month, in an extended issue of *Net Work*, we look at the vitally important issue of trust in online purchases and reviews.

One of the core principles of successful sales and marketing is the need to answer a certain question that buyers unconsciously ask themselves before they commit: 'Why should I trust you?'. That nagging uncertainty and lack of confidence is a barrier to buying, and smart sellers know that they must break down that barrier before achieving a successful sale. Hence the flag-waving claims of 'Established 50 years' or 'Thousands of customers served every day', perhaps displaying a trade body logo, showing off some illustrated case studies or glowing testimonials. If those claims are true then the product or service must be alright, mustn't it? Done properly, marketing measures like these dispel doubt and give potential customers the rosy feeling that they are making the right choice.

There has of course been a seismic shift in the last 20 years towards the two-dimensional world of online shopping, where it's second nature to source products and local services. In the UK, the home improvement sector is valued at some £4bn a year, and online trade directories such as **RatedPeople.com**, **CheckaTrade.com** and **MyBuilder.com** have sprung up to steer consumers towards local firms whom they claim are monitored and vetted for quality. Potential buyers pore over details, feedback and reviews, and they check star ratings before engaging a trader. The directories vet their members themselves, though RatedPeople also highlights the government-backed TrustMark quality-assurance scheme (**www.trustmark.org.uk**) that may apply to some of their traders. Some, more progressive traders, may hold more rigorous SafeContractor accreditation instead. One question worth asking, though, is 'Who checks the checkers?' Following consultations and investigations by the UK's Competitions and Markets Authority (CMA) five years ago, to counter the possibility of fake reviews or the deliberate withholding of negative ones, both CheckaTrade and rival TrustATrader agreed to tighten up their internal review procedures.

Seeds labelled as 'rings' and 'bracelet' mailed from China to the US as part of a brushing scam. They have not so far proved hazardous. [Image: Washington State Department of Agriculture/Facebook]

As far as buying physical goods is concerned, if things don't work out then EU consumer law (enshrined in the UK's Consumer Contract Regulations) provides for a 14-day return period, so you could always send stuff back for a refund (including the *original* basic postage charges), if you don't mind the hassle of returning them at your expense (unless they are faulty). Remember also that UK PayPal transactions don't have the same consumer protection that buying directly using one's own credit card would, especially for items costing over £100.

For many online sellers, the problem of cementing 'trust' is dealt with by offering star ratings and reviews. We have become conditioned into relying on them before taking the plunge, but how trustworthy are the reviews themselves? Some very underhand tactics can be used to try to garner positive reviews and distort the picture in a seller's favour.

The seeds of doubt

Earlier this year, people around the world started receiving mysterious little packets of seeds that they knew nothing about. The bags from China were often labelled as 'beads' or 'jewellery' but contained small bags of seeds instead, causing not a little consternation and alarm to their recipients. As you would expect, rumours soon swirled around on the web: were the seeds a genetically modified biohazard or an act of 'agro-terrorism'? Did they contain dangerous pathogens? What would happen to the nation's food chain if they germinated?

In Britain, there was even speculation that the seeds might be Japanese knotweed, a destructive bamboo-like plant notorious for undermining foundations and wrecking property! According to the US Dept. of Agriculture (USDA), people from every US state received them, and by the end of August worried citizens had sent some 8,500 packets to the USDA for analysis. So far, though, more than 320 seed varieties have been identified but no biohazard has been found, says the USDA. The puzzling packages have not been limited to seeds, either. Other cheap, unsolicited goods turned up, including flashlights, handwarmers, ping-pong balls and a small keyboard vacuum cleaner that all turned up unannounced, according to America's Better Business Bureau. What was going on?

The packages were deemed part of an ongoing scam that we first saw in Britain two years ago, in which unscrupulous traders (usually third-party Amazon sellers) hijack the IDs of individuals and set up bogus customer accounts using them. The rogue sellers then anonymously mail out low-value goods to the individual's address, which allows the seller to chalk up the delivery of a 'successful' (but bogus) transaction. The scam, called 'brushing', then enables phony sellers to post fake positive reviews about themselves, important because as we all know, good reviews create an impression of trustworthiness. Vendors selling through Amazon have been heavily implicated, but other online retailers have been affected too.

Beware geeks bearing gifts

It is easy enough for Chinese vendors to sell to the West via eBay and Amazon or through portals like AliExpress and Banggood. The level of trade circulating in China is truly enormous: I wrote in 2019 how, on China's 'Singles Day' alone, the volume of trade was

CH¥ 213.5bn (£24bn, US$30bn), and that's just on Alibaba. To get an idea of the scale of industry, some YouTube videos offer insights into some Shenzhen-based blocks that are described as the world's greatest electronics markets. They're crammed with myriad sales booths, retail counters and more besides, all dedicated to selling gadgetry and electronics technology (see **https://youtu.be/kaKVSANVMRI**)

Eager to build up credibility and sell their wares to the West, Chinese vendors have taken to offering reviewers free or discounted goods in return for customers submitting a favourable Amazon review. The offer may come in the form of a WhatsApp message or a discrete voucher tucked in with the goods, maybe offering the chance to join a 'VIP Program' and tantalising buyers with the offer of more free goods. A whole trade sector has also sprung up that specialises in furnishing their clients with rosy product reviews.

Millions of reviews are checked and posted online every week and disreputable sellers may also try to remove poor ones. At the start of the year I sourced a wildlife camera from an Amazon seller in China. It exceeded expectations, but I then received a request to give them a five-star review, along with the offer of a full refund on another model (ie, a free product) subject to a favourable five-star review appearing on Amazon. One Amazon UK reviewer left a scathing two-star review of a China-sourced appliance and then wrote: 'I [then] received a [personal] email from someone asking me to remove this review or change it to five stars in exchange for a £40 refund in an attempt to raise the rating of their product... I refused the offer and lowered my review from five stars to one star and reported it to Amazon.'

A Google Chromecast dongle that allows media to be cast to the TV through its HDMI port. It also needs a power source. [Photo: author]

Fake reviews are not a new problem: four years ago the Competitions and Markets Authority shut down an Internet marketing firm that posted fake reviews to boost their client's online profile. In an effort to combat dodgy reviews, Amazon UK recently took down no less than 20,000 of them, written mostly by a handful of Amazon's 'top reviewers'. One contributor submitted a five-Star Amazon review of various Chinese products every four hours on average. The *Financial Times* newspaper then revealed that he had resold many of the goods on eBay. The reviewer denied any wrong-doing and claimed they were duplicate, unopened goods. Amazon states it has 8,000 staff processing reviews and rigorously takes steps to prevent feedback from being manipulated.

Not so starstruck

Most traders are honest though, and some vendors on Amazon now face an even bigger problem: fake one-star reviews that are posted onto their product pages by dishonest rivals in order to derail their business. It doesn't take much to scare off an unsure buyer and a handful of one-star reviews can sink a legitimate business almost overnight. 'Business fell off a cliff', said one such maligned seller who gave it all up as a bad job. eBay sellers have similar issues when chasing down malicious Detailed Seller Ratings (DSRs) intended to harm their sales.

Floor to ceiling electronics: a look inside ShenZhen Huaqiangbei Electronics Market (Image: Nikolay Tanev / YouTube)

Over time, one learns to take reviews and feedback with a pinch of salt. One excitable reviewer on Amazon left nothing but five stars for every purchase, possibly to convince herself about her decision to buy them in the first place. Recently, several Amazon customers had problems with facemasks not arriving from a European seller: after complaining directly to the seller, they posted five-star reviews just because the vendor promised (hurrah!) to send some more. We'll never know if they arrived because the seller's account got shut down by Amazon. Five stars too for some photo paper: 'I haven't used it yet but since Epson quality is reliable I imagine it will be just as good as it was last time. No complaints at all.' A four-star review for spraypaint said 'Seems good, but I have not used it yet,' while another one marked down an electric fan to one star, stating 'Fan no good because it only blows air around, it does not cool it down.' A helpful five-star review too for a Christmas gift: 'Cannot review as not used yet, bought as stocking filler for Xmas.' The comedy goes on.

Before buying, probably the best tactic is to check the most recent seller feedback and look for suspicious patterns such as a flurry of five-star (or one-star) reviews all dated roughly the same time. With experience, and maybe after suffering the odd setback, online buyers are learning to become much more sophisticated and discerning when shopping online.

A king's ransom

Last month, I highlighted how ransomware had hit Blackbaud, a popular services provider that hosts web services on behalf of many institutions

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NVidia's Shield TV is a powerful Android-based digital media player for demanding users and gamers. It has Wi-Fi and Ethernet, and works with Alexa and Google Assistant.

around the world. Blackbaud joins an increasing number of victims that decided to pay the ransom. For their 2020 report, *The State of Ransomware*, security specialist Sophos commissioned an independent survey of 5,000 IT managers in 26 countries and the results were quite surprising. They found that 51% of respondents had been hit by ransomware in the last year, but increasingly the main targets of the 'smart' criminals were now server-based systems rather than small operators.

Of those affected by ransomware since 2019, over 70% of respondents had at least *some* data encrypted but 94% managed to get their data restored. Big business has insurance covering such losses but, interestingly, Sophos found that it was ultimately twice as expensive to pay a ransom instead of restoring systems from backups and dealing with the fall-out. In Spain, just 4% paid the ransom and 72% restored from backups, but in India 84% of respondents had been hit and 66% of them paid the ransom. Overall, just 1% who paid a ransom did not get their data back – maybe a sign of 'honourable thieves' finding that they can rake it in by offering a 'professional' service. (Download the 2020 report from Sophos at: **http://bit.ly/pe-nov20-sophos**)

Tune into Android TV

The way we access TV entertainment is changing, thanks to Internet access, smart apps, streaming services and Freeview 'Play' TV. Home network users who enjoy the likes of Netflix, YouTube, Amazon Prime or catch-up TV will know that an ordinary 'dumb' HDMI TV can access streaming content by adding a powered HDMI Wi-Fi dongle. Amazon offers a remote-control Alexa-powered Fire TV Stick 4K UHD (£50), and smartphone apps and voice controls make it easy to queue up content for casting onto the TV. Google offers their Google Chromecast dongle (£30) or 4K Chromecast Ultra (£69) and Android apps are great for queuing up and casting YouTube content from a phone or tablet onto the big screen.

These HDMI dongles can give older TVs another lease of life. Whether to buy into Google Nest or Amazon's Fire depends on how deeply you are wedded to either eco-system. I have three Google Home Minis (the second generation is called Nest Mini) dotted around because I frequently google for answers, definitions, reminders, the time or the news. A Google Nest Hub on my desk handles voice search and displays 'written results' on its LCD screen: it's a great desktop tool for a busy internet worker. I have just one Amazon Echo Dot to ask 'where's my stuff?', though 'skills' can be added to interface with many IoT devices or automate other tasks (the same being true of Google Nest apps). Of the two systems, Amazon's offer is probably more family friendly all round and I sense that it slightly has the edge. Frequent googlers (or those who use, for example, Google Calendar) will prefer to use Nest, which is configured by the Google Home app.

Add-on HDMI dongles like Chromecast also give you a fighting chance of 'outsmarting' troublesome smart TV apps by using smartphone apps instead. For example, the author discovered his ageing Samsung smart TV simply refused to run the My5 'catch up' TV app anymore: the TV just locked up. The My5 app for Android ran perfectly on a smartphone and enabled Channel 5 programmes to be cast to the Chromecast dongle instead. There was no reply from Channel 5 when I pointed this out.

Google is releasing a new HDMI dongle probably called Google Chromecast with Google TV. The fully-fledged Android TV device has a remote control and incorporates the usual streaming apps along with a D-pad, buttons for YouTube, Netflix and support for Google Assistant and Google Play apps and games. It's expected that 'unlisted' Android apps can also be sideloaded onto the dongle. Release dates, prices and technical specs are sketchy, but it's worth watching out for as a way of adding extra Android functionality to an HDMI TV.

Other streaming media players include the Xiaomi Mi TV Stick (£35, **scan.co.uk**) which runs Android 9.0 and its basic remote control has buttons for Google Assistant, Netflix and Amazon Prime; devices from Roku start at £30 and rumours circulate of a forthcoming Nokia-branded Android TV dongle as well. For network-hungry users or gamers, there's the NVidia Shield, a powerful Android TV media streaming and gaming device that works with Alexa and Google Assistant and has Chromecast 4K built in, along with 2.4/5GHz Wi-Fi and gigabit Ethernet. It offers HD-to-4K upscaling using AI. Prices start at a penny under £150.00. Full specs and details of the pricier Pro version are at: **www.nvidia.com/en-gb/shield/**

Other news

The speech recognition and context-awareness skills of Alexa and Google Assistant are extraordinary, but did you know that all your speech queries and clips are memorised in their systems? To review your Alexa voice commands, open the Amazon Alexa app on your smartphone and go More/Settings/Alexa Privacy. There you can review Voice History and delete any recordings from memory. You can also enable 'Deletion by voice' and Alexa will erase recordings on command. Instructions to delete Google Assistant recordings are at: **http://bit.ly/pe-nov20-google**

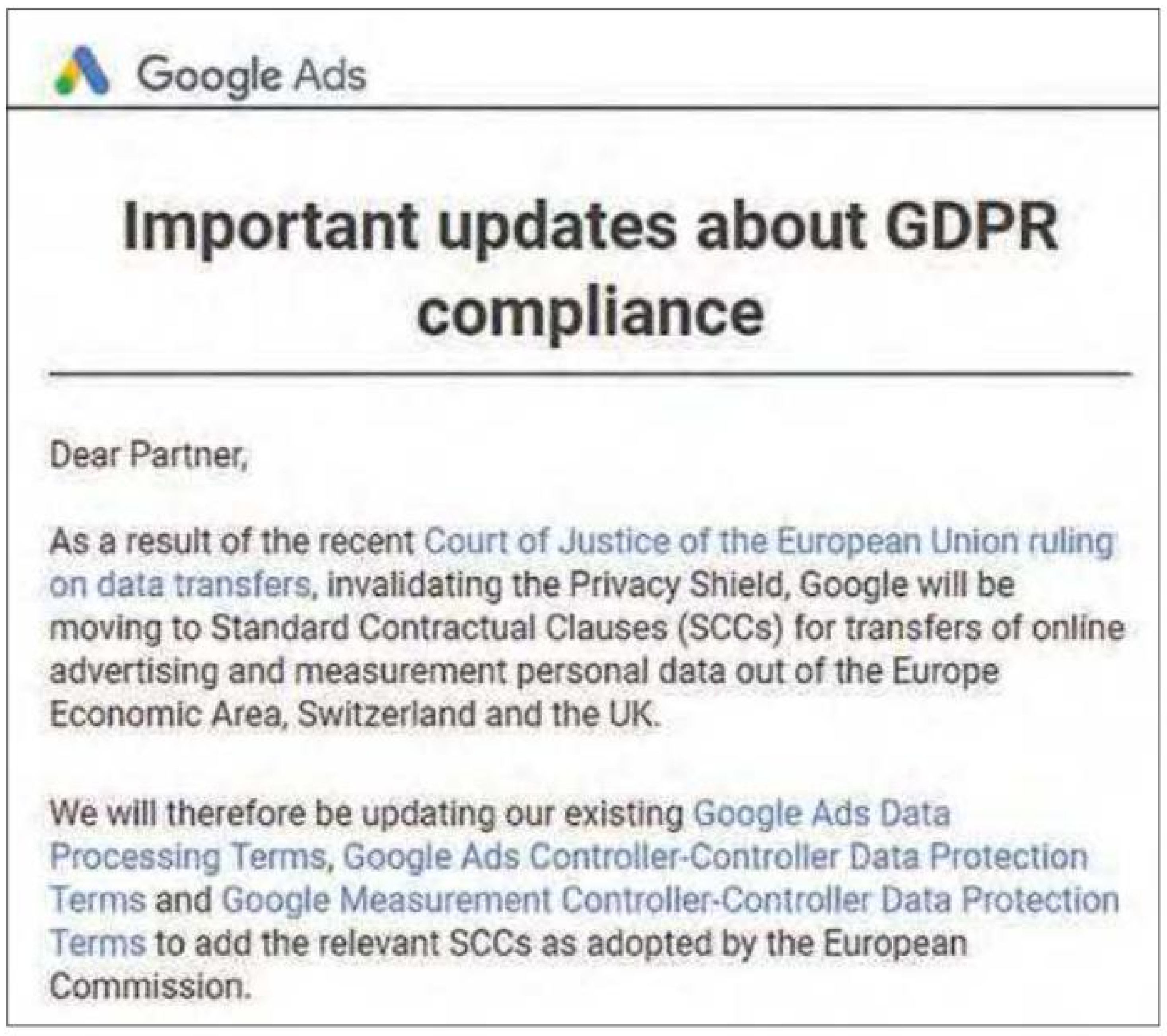
Chinese video clip giant TikTok, which like Huawei has come under fire from the US Government, has announced its first European data centre will be built in Ireland at a cost of about €420 million. TikTok is also rumoured to be considering building its HQ in London, but perhaps the outcome of stormy UK/EU Brexit negotiations, due to conclude in mid October, may cause a re-think. TikTok was threatened with an outright ban in the US due to fears of personal data being exfiltrated to mainland China. In September, the US approved an effective takeover of Tik Tok's US operation by Oracle and Walmart.

The status of current Huawei smartphones is now becoming less clear, despite earlier assurances that existing Huawei devices would continue to receive Google updates. The author's Huawei continues to update, but extended US licences that permitted Google to keep apps refreshed expired in early August. The US has also choked off supplies of semiconductors to Huawei and is considering sanctioning other foundries too. Huawei is far from finished; it has developed its own OS called Harmony and is rapidly building up its own library of apps including signing up TomTom. Meantime, the US faces a bill of some $1.8bn to rip out and replace telecoms equipment that 'poses a national security threat' – mainly, hardware made by China's ZTE and Huawei.

Ironically, America, in turn, has had its own data protection standard (Privacy Shield, formerly Safe Harbor) invalidated by the EU. This follows a legal case dubbed 'Schrems II' (see *Net Work*, August 2018 for background) which ruled that America's own privacy controls still failed to adequately safeguard EU data subjects from US surveillance. As a result, many readers will have seen emails from Facebook, Google and others concerning the use of so-called SCCs instead – Standard Contractual Clauses cover the transfers of personal data out of the Europe Economic Area, Switzerland and the UK. The use of SCCs has been allowed by the EU for the time being, but further negotiations will have to be hammered out with neither side showing signs of giving way.

Disappointment for those awaiting the launch of the new Intellivision Amico TV games console (*Net Work*, August 2020). Disruption caused by Covid-19 has resulted in the postponement of the launch until April 2021.

Proposals made four years ago by Facebook and Google to build a new undersea cable between the US and Hong Kong have been banned by US authorities, due to ongoing security concerns. Revised plans for a cable connecting the Philippines and Taiwan instead have been re-submitted.



Google Ads

Important updates about GDPR compliance

Dear Partner,

As a result of the recent Court of Justice of the European Union ruling on data transfers, invalidating the Privacy Shield, Google will be moving to Standard Contractual Clauses (SCCs) for transfers of online advertising and measurement personal data out of the Europe Economic Area, Switzerland and the UK.

We will therefore be updating our existing Google Ads Data Processing Terms, Google Ads Controller-Controller Data Protection Terms and Google Measurement Controller-Controller Data Protection Terms to add the relevant SCCs as adopted by the European Commission.

America's Privacy Shield data standard (formerly Safe Harbor) has been invalidated by the EU over privacy and surveillance concerns. Standard Contractual Clauses (SCCs) are being implemented in its place.

...and in space

In early September, SpaceX successfully launched its twelfth Starlink mission, lobbing another 60 Starlink satellites into LEO (low earth orbit), making roughly 650 to date. The mission's first stage landed for a second time on the SpaceX drone ship, *Of Course I still Love You*.

Swarm Technologies successfully launched their first 12 SpaceBEE microsatellites on 2 September (*Net Work*, Oct 2020). A total of 150 of the 400 gram saucer-sized SpaceBEEs are destined to circle the earth and offer low-cost connectivity for IoT devices in agriculture, marine and more. You can track the SpaceBEE coverage at: **https://swarm.space/leo-labs-globe/.**

That's all for this month's roundup – see you next month for more *Net Work!*

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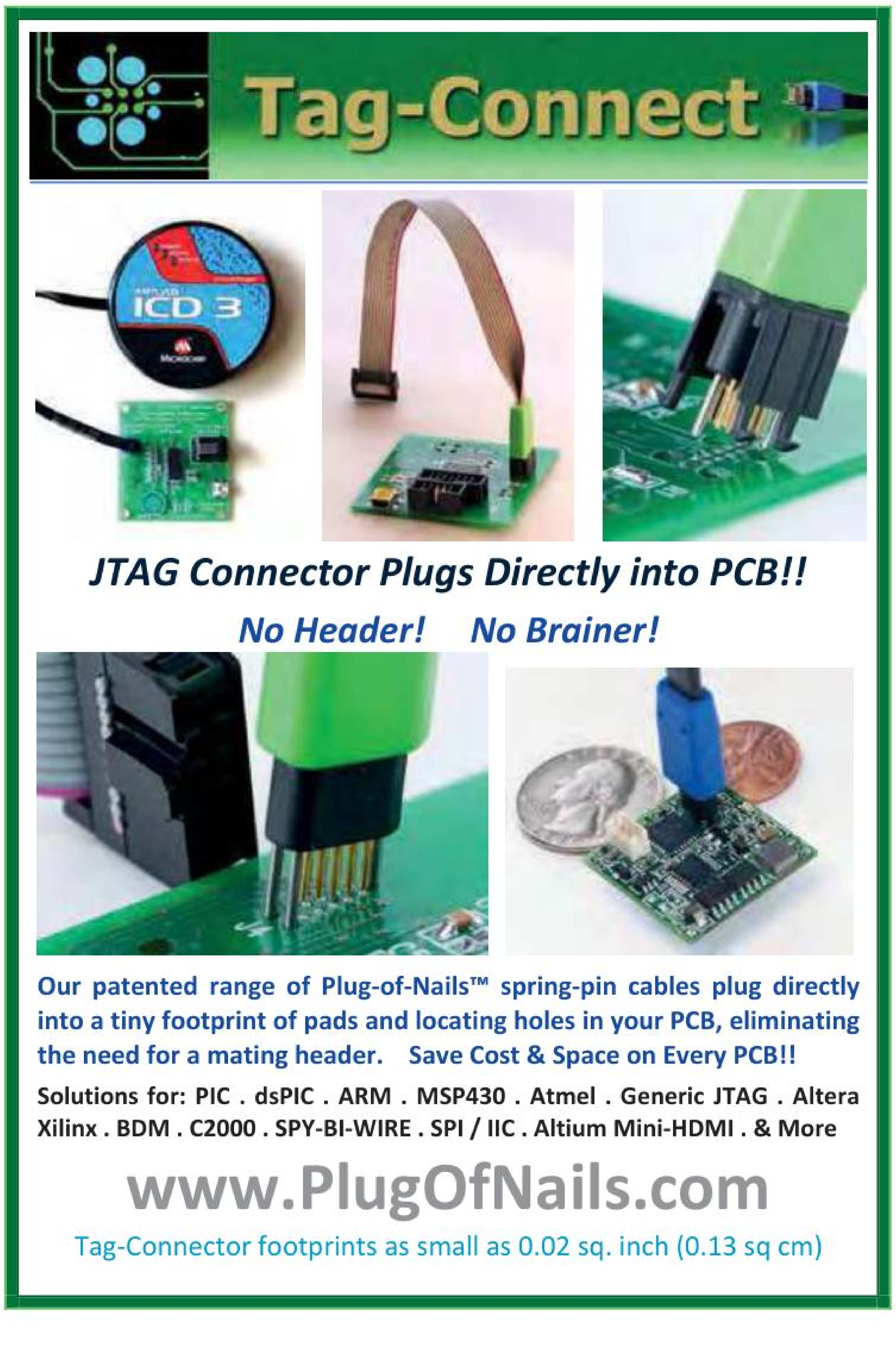

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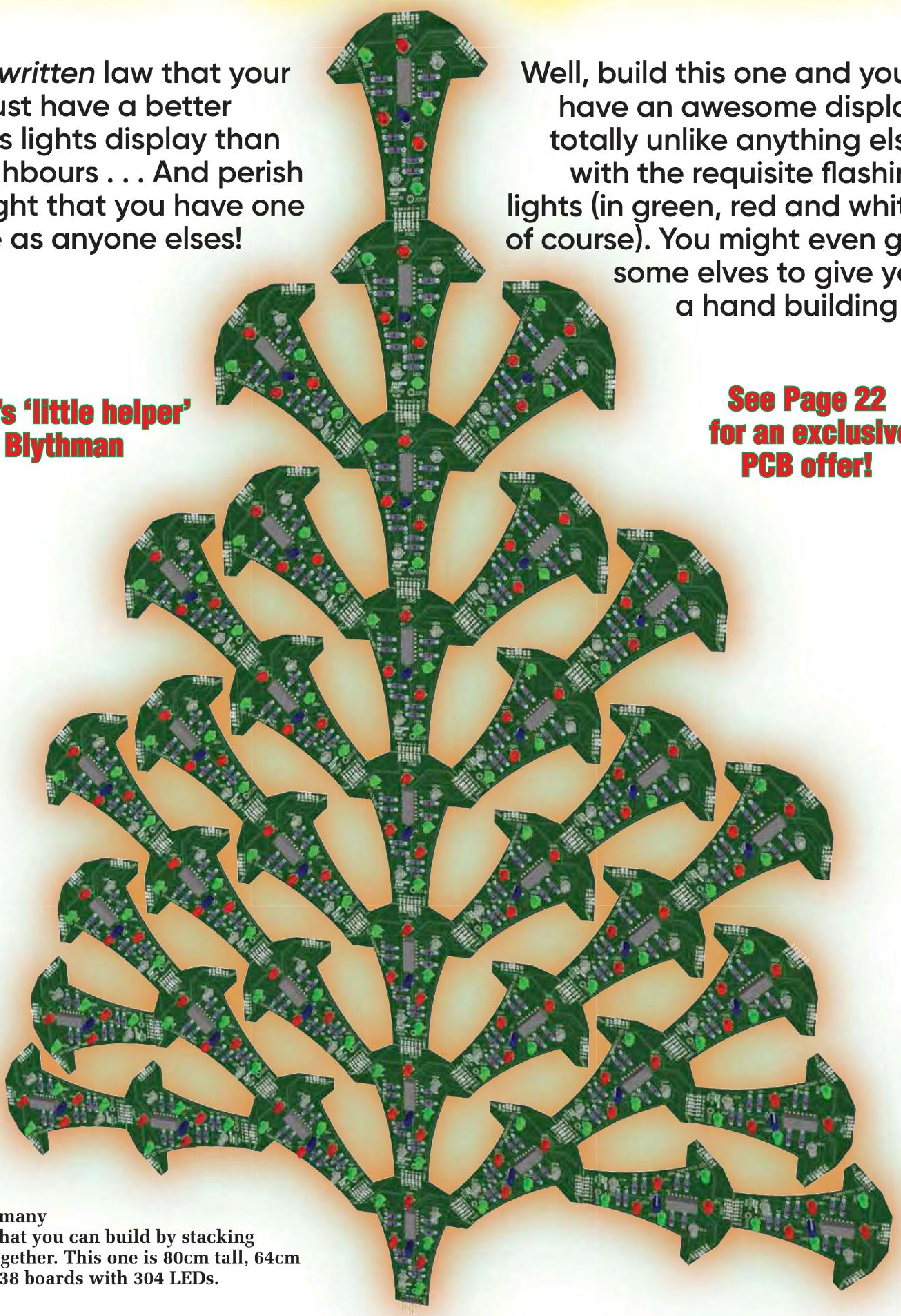
The Christmas Tree that grows!

It's an *unwritten* law that your house must have a better Christmas lights display than your neighbours . . . And perish the thought that you have one the same as anyone elses!

Well, build this one and you'll have an awesome display, totally unlike anything else, with the requisite flashing lights (in green, red and white, of course). You might even get some elves to give you a hand building it.

By Santa's 'little helper' Tim Blythman

See Page 22 for an exclusive PCB offer!



Just one of the many possible trees that you can build by stacking these boards together. This one is 80cm tall, 64cm wide and uses 38 boards with 304 LEDs.

And just how does it grow? Surely it's not alive? Well, not quite – but it can grown from a single tree about 150mm high to a monster – as high as you want.

The reason for this is that it's made from stackable PCBs – you just build another board and plug it in! And each one is cheap and easy to build, so it won't take much effort to make a big tree display.

The concept is simple – but ingenious! Each PCB is shaped like a small tree with three branches and has eight LEDs which can be controlled in any manner that you wish, to create many different kinds of patterns.

Not big enough?

If you want more, another three PCBs can be connected to the end of each branch, then another three PCBs can be stacked on those branches and so on, to form a bigger and bigger tree.

When the PCBs are stacked, power and data are automatically fed through, so you need just one low-cost controller board no matter how big your tree is.

If you want a huge Christmas tree, you could use, say, 38 boards, as shown opposite, to make a big 'pinetree'-shaped arrangement the best part of a metre high, with a total of 304 flashing LEDs. Wouldn't that look absolutely spectacular?

Want even bigger?

Hey, the only practical limit is how you are going to support a 20m high tree . . . and supplying enough power for the number of PCBs.

(Each one draws about 25mA, so a huge tree is going to need a few amps @ 5V. Now *there's* a practical use for that old computer power supply gathering dust in the cupboard!)

You could even collaborate with your friends, family and/or classmates, by each building a few boards and then bringing them all together to build a huge tree.

It's also an excellent project for beginners since it's easy, fun and safe, using low voltage – and you can learn about electronics at the same time.

How it works

Each board contains eight LEDs with current-limiting resistors, one IC, one capacitor and four optional headers (to connect further boards).

The IC is the key to this clever design. It's a 74HC595 eight-bit shift register with output latches. That's a pretty complicated description; but in fact, the way it works is actually relatively simple. So first, let's discuss the IC's output latches.

A latch is a circuit with one digital input, one digital output and a latching signal line. When you send the latch signal, the output state is set to the same as the input state (either low or high).

It stays that way until you send another latch signal. So if an LED is connected to the output of a latch, you can set it to be either on or off, and it will remain that way until you decide to change it.

If we connect all the latch signal lines together, we create a single wire, which can be used to update the state of all the LEDs simultaneously.

Therefore, we can update the latch inputs several times per second and then trigger the latch signal lines, setting the state of each particular LED on or off as desired, and they will stay in that state until another update comes along. This lets us create the LED patterns on the tree.

Shift registers

So how then do we control the state of each latch input to select the LED on/off states?

We *could* use a parallel scheme with one wire per latch, but then in the case of the large tree opposite with 304 LEDs, we would need 304 wires (plus a few for the latch signal, ground, power...) and that would be far too unwieldy.

This is where the shift registers come to the rescue. In addition to eight separate latches to drive eight LEDs, each 74HC595 logic IC also contains an eight-bit shift register.

You can imagine this like a clear plastic tube which can hold eight coloured balls.

Imagine the balls are black or white to represent zero and one bits, as shown in Fig.1. If you push a new ball (of either colour) into one end of the tube, they all move along one position, and the last one falls out the end. If you feed eight new balls into one end of the tube, one at a time, once you have finished, all the old balls will have fallen out and the resulting black/white pattern will be determined by the order in which you inserted the new balls.

Now, if we place several of these tubes end-to-end, we can keep feeding in balls into the first tube and eventually, we will have replaced all of the balls in all of the tubes.

This is essentially how our chain of shift registers works. We feed bits into the first register in the chain, one at a time, and they are 'shifted' through the first register. Each time, the bits stored in the register move along to the adjacent bit position and the last one, which would be lost, is presented at one of the IC outputs.

This can then be fed into the next register in line.

So we only need two 'data' wires – a clock signal (to indicate when to shift the bits) and a data signal (to indicate the value of the new bit to feed in) and we can update any number of registers.

We just need to send exactly the right number of clock pulses. These shift registers feed into the latch inputs mentioned earlier. So after shifting all the required bits into the registers, we send the latch signal and all the LED states are updated with the values that we just transferred serially (ie, one at a time).

Connecting and arranging multiple boards

If we were trying to create an LED bar graph – ie, where each set of eight LEDs is simply stacked next to the last – then we could simply wire up the boards so that the output of each shift register feeds into the input of the next.

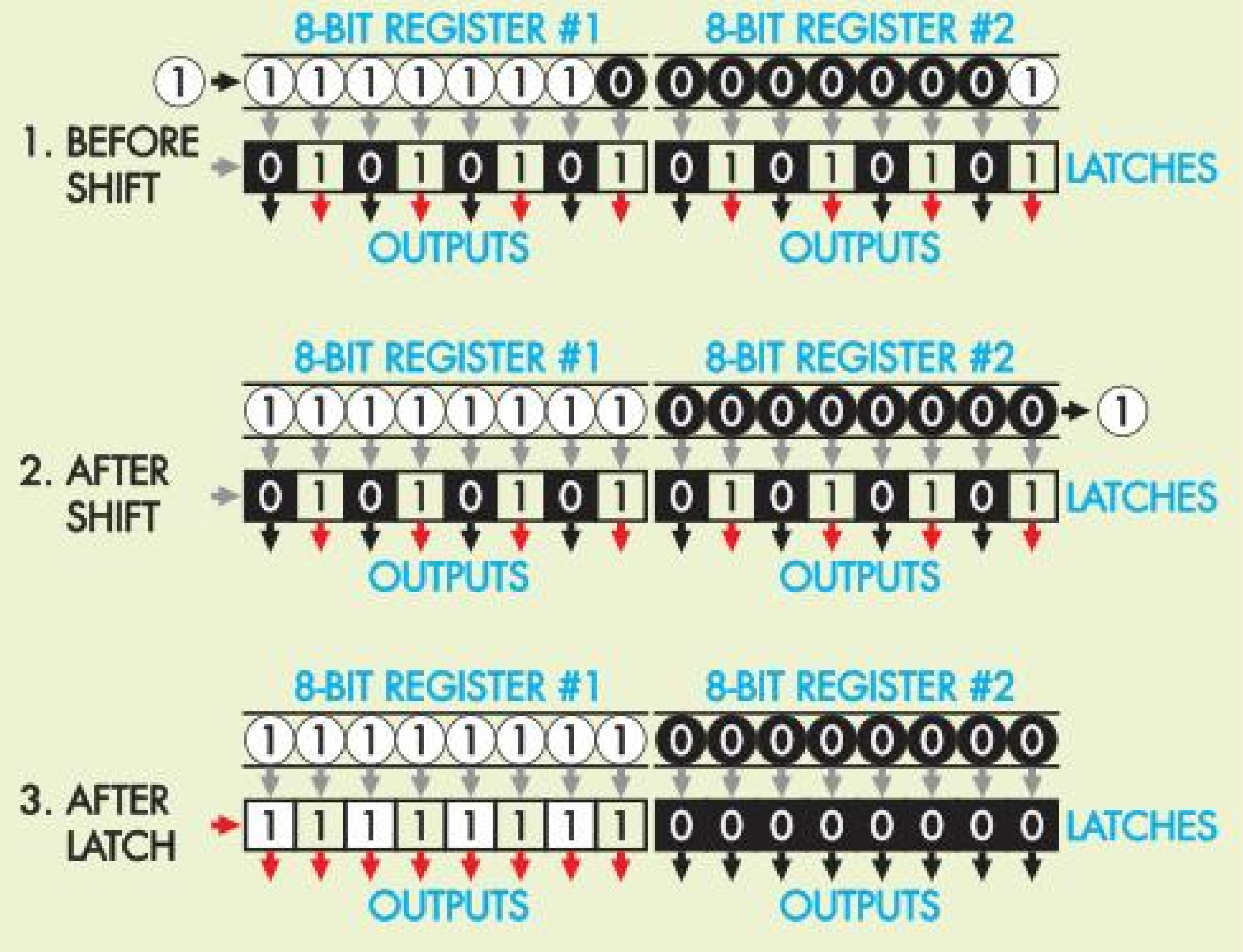
Then we could easily update all the LEDs arranged in a row by sending an appropriate number of serial pulses.

But a tree is not linear – it has branches – so we need to be a bit more cunning in how we wire the boards up.

Our tree board has one input connector, to update the eight LEDs on the board itself, plus three outputs, going to each of the three possible branches. And you might not fit all three branches. In fact, for the 'leaf' boards at the outside edge of the tree, none of the branches would be fitted.

So how do we make the shift register chain work? We use something which is known in mathematics as a

Fig.1: this shows how a shift register with output latches works. Here, two 8-bit shift registers are chained to effectively form a single 16-bit shift register. When a new '1' bit is shifted in from the left (at the first register's input), all the bits shuffle to the right by one step. Then, when the latch signal is applied, the new values within the shift registers are copied to the latches and thus the output states change.



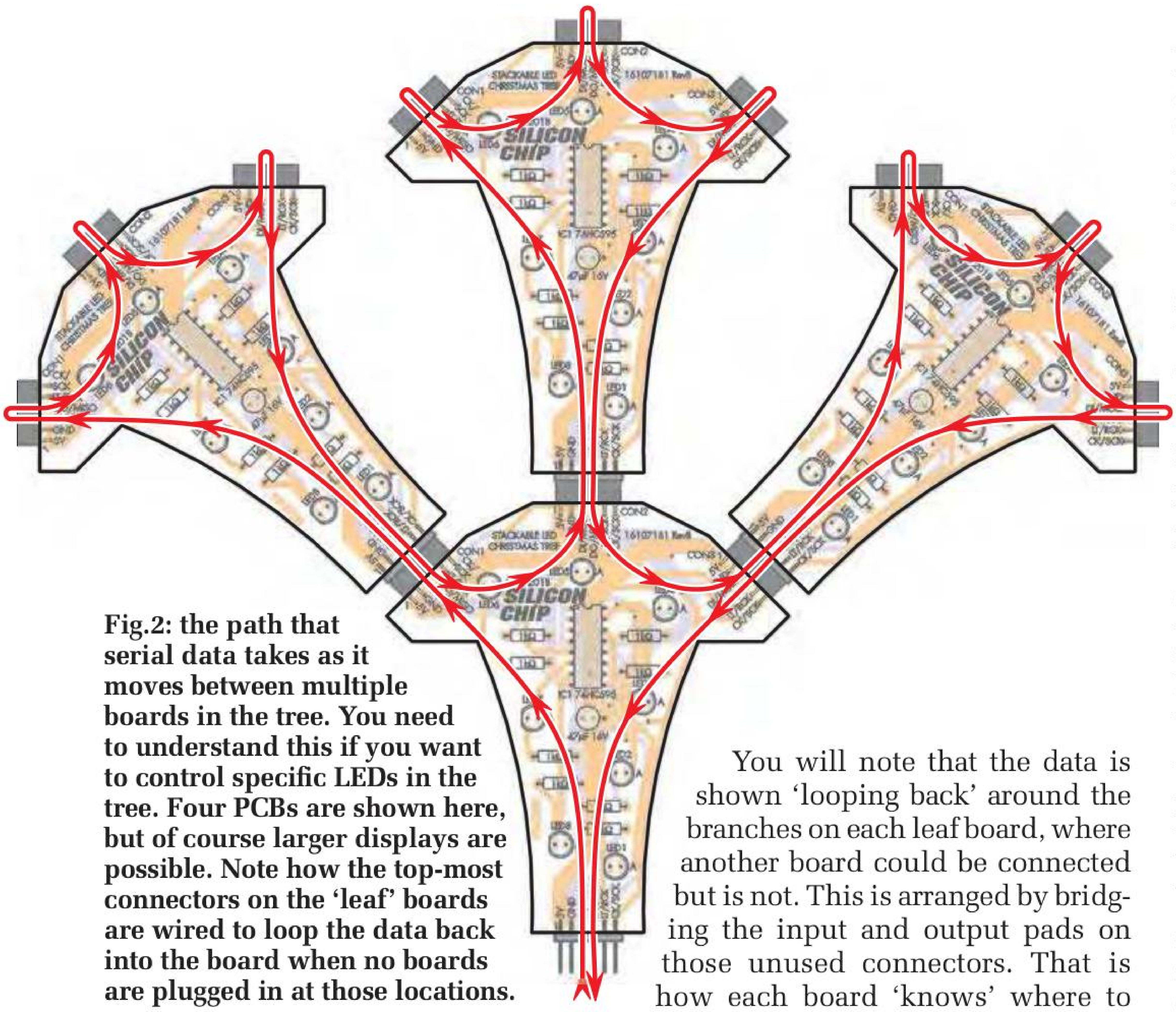


Fig.2: the path that serial data takes as it moves between multiple boards in the tree. You need to understand this if you want to control specific LEDs in the tree. Four PCBs are shown here, but of course larger displays are possible. Note how the top-most connectors on the 'leaf' boards are wired to loop the data back into the board when no boards are plugged in at those locations.

'depth-first' algorithm. Imagine you have a tree made of four boards, as shown in Fig.2.

There is one 'root' board, plus three 'leaf' boards attached to each of the root's branches.

Data is first shifted into the eight-bit register on the root board. Its output is then fed to the first leaf board, where it is shifted into the eight-bit register there. The output of this first leaf board is then fed back into the root board, and then into the second leaf board.

It is then shifted through the third eight-bit register, then back into the root board, to be passed onto the fourth and final eight-bit shift register. It then returns to the root board and goes out the bottom.

That data is ignored since it will be the old data, which is no longer needed. But it must go out the bottom in case there is another layer of boards which is underneath.

You will note that the data is shown 'looping back' around the branches on each leaf board, where another board could be connected but is not. This is arranged by bridging the input and output pads on those unused connectors. That is how each board 'knows' where to route the signal.

You would agree that this is a pretty clever way to get data to all the parts of the tree with minimal effort and virtually no wiring.

The next question is where does the data come from in the first place? You could use a variety of different sources, such as an Arduino or Raspberry Pi, but next in this issue, we will present a very simple and cheap control module.

This can be used independently, with pre-programmed patterns, or connected to a computer via its USB port and used in conjunction with computer software to drive the LEDs on the tree.

We will also provide instructions on how to control the *LED Christmas Tree* using an Arduino later in this article.

Circuit details

The circuit of each root/branch/leaf board is identical and is shown in Fig.3. IC1 is the 74HC595 shift register and its latch output pins are labelled Q0 through Q7. Each of these is connected directly to the anode of one of LEDs1-8, so if the latch output is high, the LED lights up.

The LED cathodes are connected to ground via 1kΩ current-limiting resistors, giving a typical current, with a 5V supply, of 3mA (5V – 2V)÷1kΩ . This is suitable for high-brightness LEDs but you may want to reduce the resistor values (to say 220Ω) if using standard LEDs, to give them enough current to produce reasonable brightness.

But this would increase the overall current demand, which could be a problem if you're using many boards to make a big tree. So we recommend that you stick with high-brightness LEDs.

A 47µF electrolytic bypass capacitor is connected across the supply pins of IC1. This is important since there are many connectors and tracks between the root and the leaves of a big tree and that could cause transient voltage drops due to wiring and contact resistance. A bypass capacitor helps to smooth out the local supply voltage

The rest of the circuit is just wiring between IC1 and the four connectors; CON4 is at the bottom of the node and for the root board, is connected to the controller. This is where the data comes in.

CON1-CON3 are on each of the three branches. On all four connectors, pin 1 is the +5V supply and pin 2 is GND (0V). These are all connected in parallel, to feed power to all the branches. Pin 5 is the latch signal and pin 6 is the serial clock signal; these are all routed in parallel to all the branch connectors, as well as to pins 12 and 11 of IC1 respectively.

When pin 12 transitions from a low (~0V) to high (~5V) , that causes the eight latches inside IC1 to be updated with the new values from the shift register. And since pin 12 of all the 74HC595 ICs in the tree are connected together, they all update simultaneously.

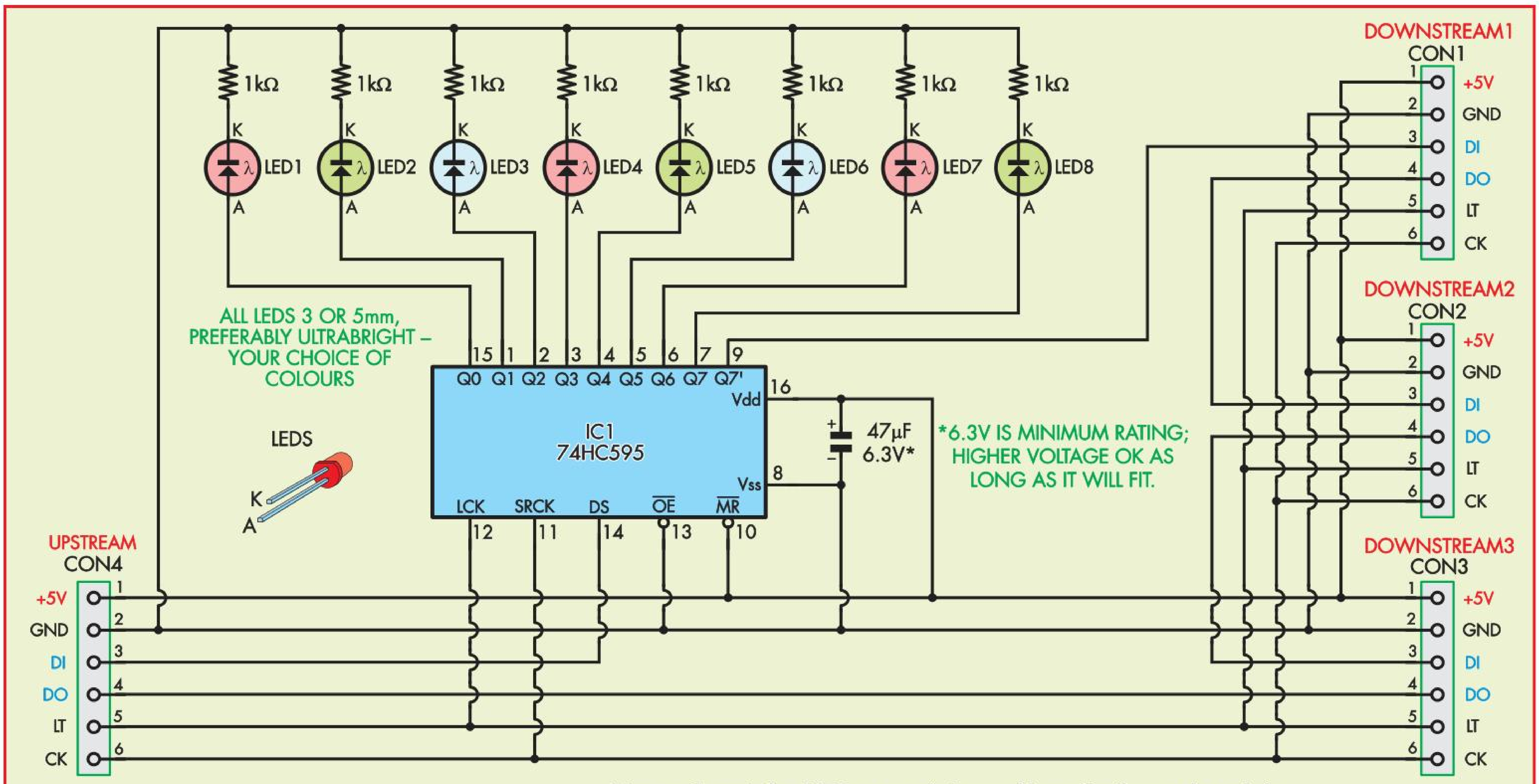
All the serial clock pins are also joined and this causes all the shift registers to shift simultaneously, forming our serial data chain. The remaining two pins are for the serial data. Pin 3 on CON4 is the serial data input and pin 4 is the serial data output.

Pin 3 is routed to pin 14 on IC1, the shift register serial data input. The serial output from IC1, at pin 9, goes to pin 3 of CON1, then the data from CON1 (pin 4) is routed to CON2 (pin 3), then from CON2 to CON3, and from CON3 back to CON4 – refer to Fig.2 to see how the data travels in the tree.

Parts List – LED Christmas Tree

(for each board – build as many as you want!)

1 double-sided PCB, code 16107181, 100mm x 93mm, available from the PE PCB Service
1 74HC595 shift register,16-pin DIL package (IC1) [Jaycar ZC4895, Altronics Z8924]
8 high-brightness 5mm LEDs (LED1-LED8; a mix of green, red and white recommended)
8 1kΩ 1/4W or 1/2W resistors
1 47µF 16V electrolytic capacitor
1 100mm length of 0.7mm diameter tinned copper wire (to join PCBs) or
1 6-way pin header ***and***
3 6-way female header sockets ***and***
3 2-way pin headers



LED Tree Display Board

Fig.3: the eight LEDs are driven directly from the eight output pins of shift register IC1, with 1kΩ current-limiting resistors setting the current through each to around 3mA.

As mentioned earlier, if there is no board connected to either CON1, CON2 or CON3 then you merely bridge pins 3 and 4 (with a short piece of wire or a blob of solder) to route the signal on to the next branch, or back up to the 'parent' node, in the case where CON3's pins are bridged. This is shown in the photo of the single board overleaf.

There is just one more pin on IC1 to consider and that is pin 13, the $\overline{G}$ input, which can be used to disable all the outputs. We aren't using this and so that pin is tied to ground. The outputs are therefore always enabled.

Controlling it

Fortunately, controlling a shift register is quite easy, although you have to be mindful of the order in which bits need to be presented.

Do keep in mind that the first bit shifted into the tree sets the state of the last LED and the last bit shifted in sets the state of the first LED.

The other thing to remember is that the data 'snakes' its way through the tree – as shown in Fig.2. If you need to know which LED is which, you will have to trace out this data path to figure it out. But many patterns can be generated where it doesn't matter exactly which LED is which.

For example, if you just want to make the LEDs twinkle, you can essentially feed random data into the tree and update the latches periodically.

Or you can take advantage of the 'snaking' pattern by slowly shifting one bit at a time and updating the latch, to make the pattern 'march' through the tree. These are both modes that our controller can provide.

Pretty much any device that can drive three digital outputs can be used to control the tree.

You can use a 3.3V-powered device, for example, a Micromite or a Raspberry Pi. However, in this case you should use a power supply voltage for the tree in the range of about 3.3-4.5V, which will result in slightly dimmer LEDs (but probably still bright enough, as long as you are using high-brightness types).

If you power the tree from 5V but use a 3.3V signal source, it may work but it's possible that it won't since with a 5V supply, the 74HC595 is only guaranteed to detect a voltage above about 3.5V as a logic high level.

Having said that, we've yet to come across a 74HC595 which

What kind of power supply do you need?

These boards are designed to run off 5V, although you could get away with running them from a slightly lower voltage.

But since 5V supplies are very common, you might as well stick with that.

If you build the boards as specified, they will draw a maximum of about 25-30mA. That means you can run up to 16 boards (500mA ÷ 30mA) off a single USB port.

Having said that, most USB ports will deliver well over the 500mA minimum and most USB chargers are capable of at least 1A – and usually more than 2A.

So you could easily run a big tree off most USB supplies – including (but not limited to) the large 38-board version shown earlier.

But there's not much to stop you from making a much bigger tree. You could combine more than 100 boards to make a huge one, well over a metre tall. You may need to attach the boards to a rigid backing for support, but it should work.

Such a tree would draw several amps at 5V.

You can, of course, buy plugpacks and 'brick' type supplies that can deliver that much current, but why not re-purpose an old PC power supply?

They will usually deliver at least 5A from their 5V rail and in some cases, much more.

A pinout of the 20-pin AT or 28-pin ATX connector will let you identify which wires are 5V (usually red) and which are 0V (usually black).

You can then cut off the unnecessary connector, join several red wires together and several black wires together, to give you your +5V and 0V outputs, and then wire a toggle switch between the green wire and the 0V output.

Toggling that switch to the on position should then cause the power supply to start up.

Note that if your power supply has a brown wire (+3.3VSENSE, not present in all cases but if it is, usually on pin 13), then you will need to join it to one of the orange wires (+3.3V) to get the power supply to stay on.

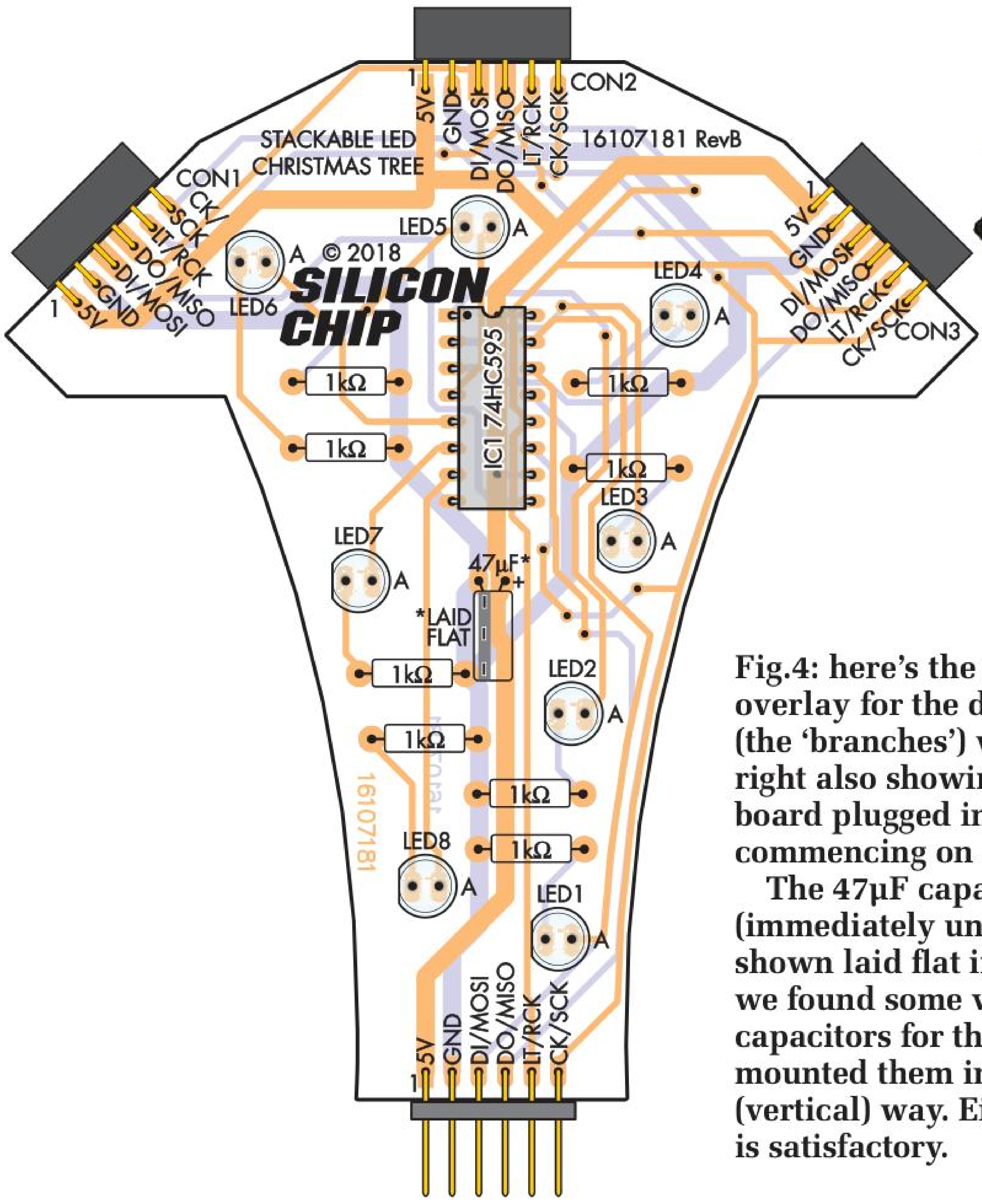
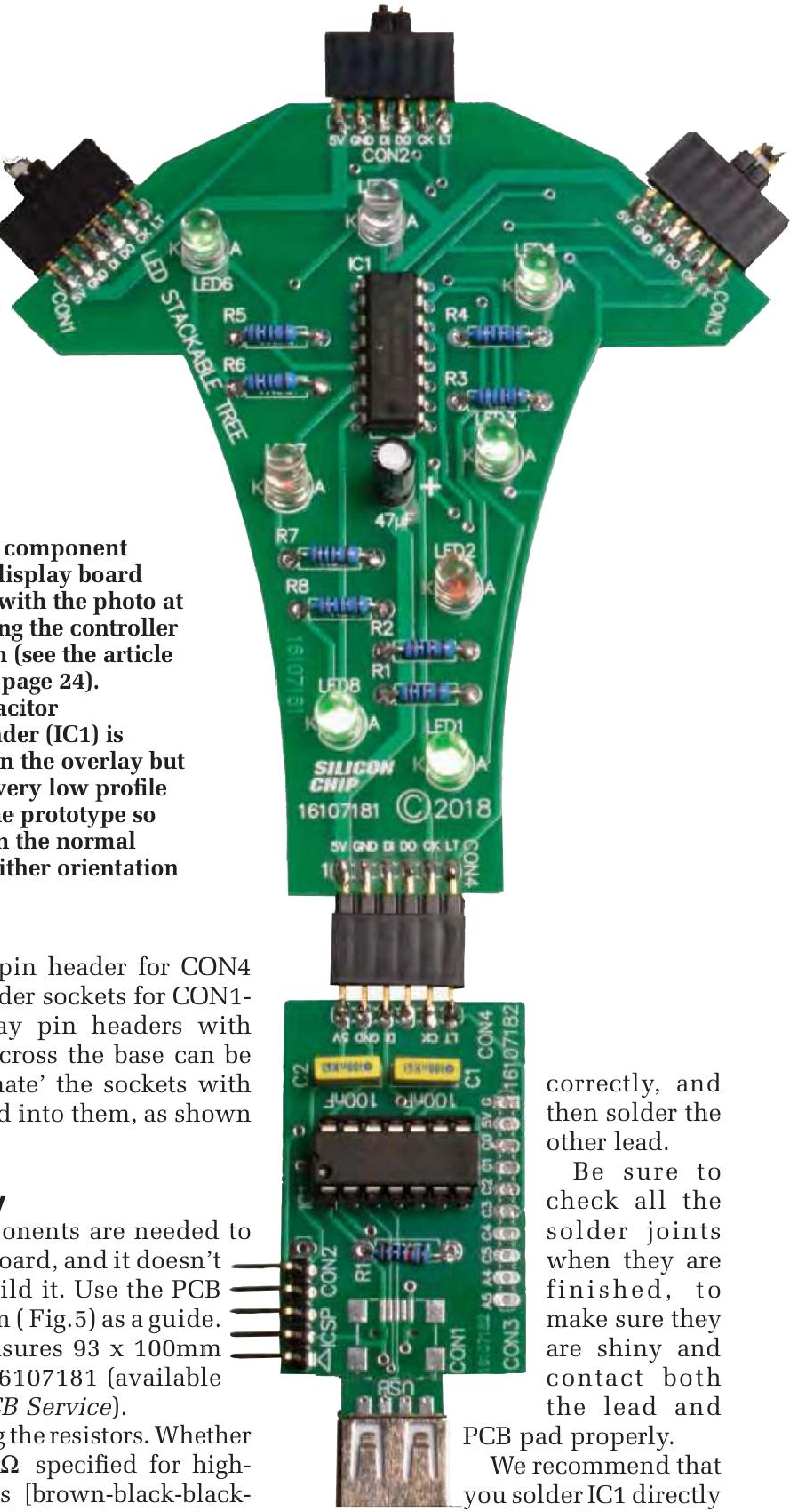


Fig.4: here's the component overlay for the display board (the 'branches') with the photo at right also showing the controller board plugged in (see the article commencing on page 24).

The 47µF capacitor (immediately under (IC1) is shown laid flat in the overlay but we found some very low profile capacitors for the prototype so mounted them in the normal (vertical) way. Either orientation is satisfactory.



will not work with a 3.3V signal. Make sure you don't feed the output from pin 4 of your tree root back to a 3.3V chip though. Generally, there is no reason to do this and also, it could damage the IC.

If you do run into problems driving the tree from a 3.3V source, you could use a logic-level translator to boost the output of your 3.3V device up to 5V. Luckily, since the control scheme is serial, you only need to translate three signals.

Connection options

Ideally, once you have built all the boards and decided on the shape of your tree, you should permanently connect the boards using short lengths of stiff wire (eg, tinned copper wire).

This makes the whole tree quite rigid and able to support its own weight, unless you are creating a real monster. For example, you could hang the tree from a wire soldered to the top. This is the cheapest construction method.

If you want to experiment and play around, you can use pin headers and sockets, as shown in our photos. That makes it really easy to experiment with the boards but you need to lay them on a flat surface for this to work.

Otherwise, if you try to stand the tree up or hang it, it will probably flop around and may pull itself apart under gravity. The sockets don't have that much retention force. So it's up to you; if you want maximum flexibility, use a six-way pin header for CON4 and female header sockets for CON1-CON3. Two-way pin headers with a solder blob across the base can be used to 'terminate' the sockets with nothing plugged into them, as shown in our photos.

PCB assembly

Very few components are needed to build a single board, and it doesn't take long to build it. Use the PCB overlay diagram (Fig.5) as a guide. The board measures 93 x 100mm and is coded 16107181 (available from the *PE PCB Service*).

Start by fitting the resistors. Whether you use the 1kΩ specified for high-brightness LEDs [brown-black-black-brown-brown (1% tolerance); or brown-black-red-gold (5% tolerance) or the 220Ω (red-red-black-black-brown or red-red-brown-gold) for standard LEDs, the values are all the same.

So all you need to do is bend their leads so they fit through the provided holes (a lead forming tool is helpful), push them down onto the board, solder the leads to the pads on the underside and trim off the excess lead length. While it doesn't matter which way around they go, it looks neater if the colour coding rings are all oriented the same way. It's also a good idea to make sure they are fitted straight, again, to make it look neat.

This is easier if you solder one lead first, then check that they are lined up correctly, and then solder the other lead.

Be sure to check all the solder joints when they are finished, to make sure they are shiny and contact both the lead and PCB pad properly.

We recommend that you solder IC1 directly in place, although you could fit a socket to the board and then plug the chip in if you prefer to do so. Push the chip right down onto the board making sure that its pin 1 notch is facing towards the left, as shown in Fig.5.

Also, make sure the IC leads go through the holes and do not fold up underneath it.

DIP ICs are designed to be installed by a machine, so their leads may be splayed outwards slightly, making it a bit more difficult to insert them by hand. If you're having trouble, try carefully bending the leads inwards slightly. You can use pliers, but a purpose-made IC lead bending tool is even better.

Install the LEDs next. You can use whatever colours you like; you could make all the LEDs on one board the same colour but different to another board, or you could mix different colours on the one board.

Regardless, make sure that each one is oriented correctly before soldering it in place. The longer (anode) lead must go through the hole marked 'A' on the PCB. We elected to push our LEDs all the way down onto the PCB before soldering and we recommend that you do the same.

Next, fit the electrolytic capacitor. It is also polarised and must be oriented correctly. In many cases this capacitor will be too tall to solder in the conventional way – it can be laid over on the board and the pins soldered down 90°. The longer positive lead must be soldered to the pad marked '+' on the PCB (the stripe on the can indicates the negative lead).

Header

As mentioned earlier, the best way to join the boards to form a big tree is with short lengths of 0.7mm-diameter tinned copper wire. You save the cost of headers that way.

You could use right-angle headers, but we have used straight headers and surface-mounted them sideways for a couple of reasons.

First, right-angle female headers are very hard to get. And second, this makes it easier for the whole assembly to sit flat.

Even if you are using fixed wires for most of the connections, we recommend that you use a female socket for CON4 on the bottom-most (root) board, to make it easier to connect up your control system.

To solder straight pin headers like this, it's easiest to hold the six-way pin header in a female socket strip. That helps to keep the pins lined up and also provides some insulation for your fingers from the heat of the iron.

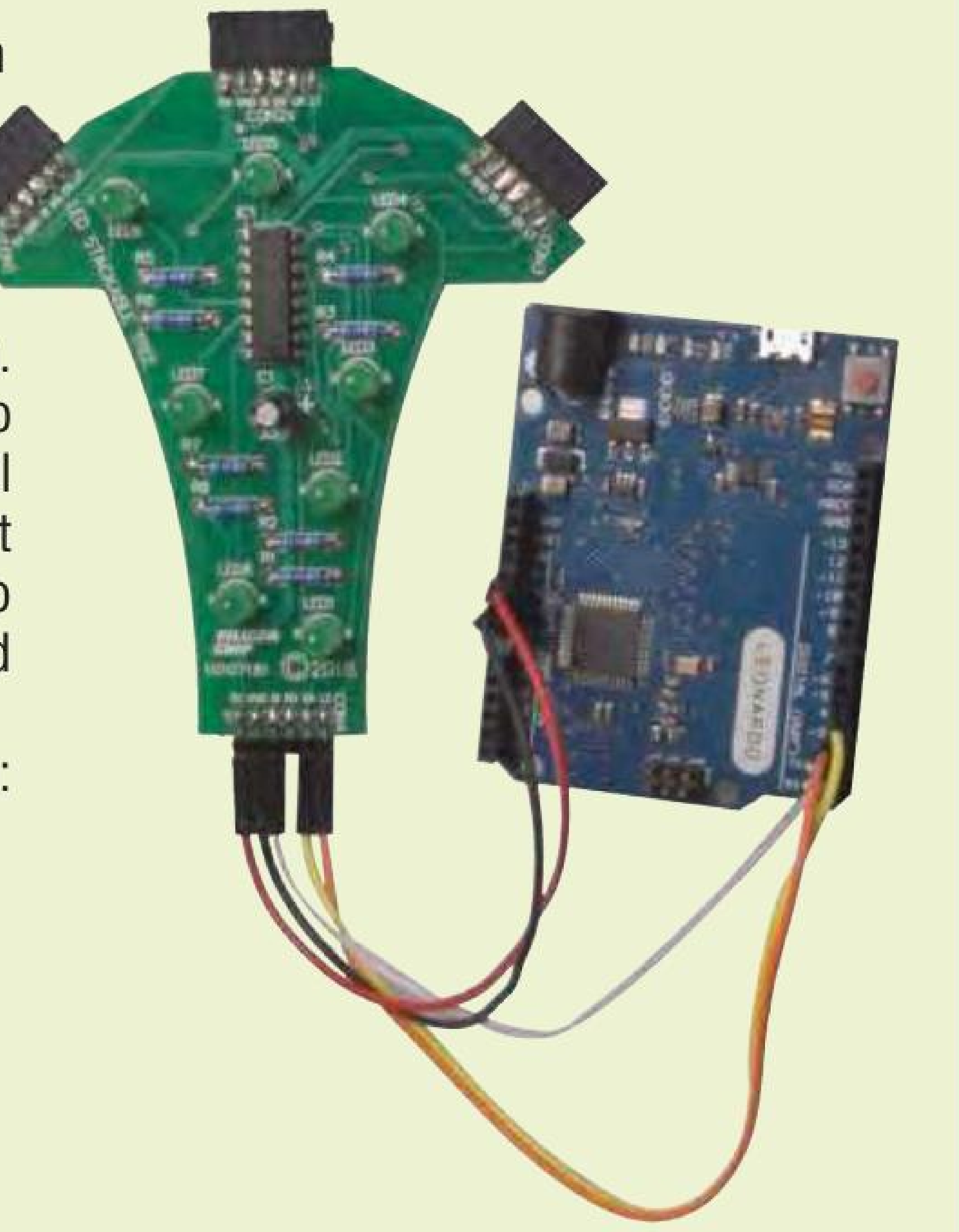
Solder one pin first and ensure the header strip is flat, level and flush with the PCB. If that is the case, solder the rest of the pins. If not, apply the iron to the soldered pin and adjust it before soldering the remaining pins.

Testing

It's a good idea to test each PCB on its own before joining them together; especially since a problem with one PCB 'branch' might affect the operation of other PCBs, making it hard to work out which one actually has the problem.

The easiest way to do this is to use the control system you plan to use for the whole tree but connect it up to one board at a time.

Controlling the LED Christmas Tree with an Arduino



We have uploaded a simple test sketch to our website to test each board you build, by cycling through the LEDs in order. It will work with just about any Arduino; we tested it with an Uno, but you can use a clone, or a Leonardo or Mega.

If you haven't used an Arduino board before, you'll also need to install the Arduino Integrated Development Environment (IDE), which allows you to write programs (called 'sketches') and upload them to the Arduino board.

This can be downloaded for free from: **www.arduino.cc/en/Main/Software**

Once you have installed this software and opened our sketch (**Stackable_LED_Tree.ino**), you will then need to make the following connections from the Arduino to your tree root using five male-female jumper leads, as follows:

Arduino Board	Tree
5V	5V (pin 1)
GND	GND (pin 2)
D2	DI/MOSI (pin 3)
D3	CK/SCK (pin 6)
D4	LT/RCK (pin 5)

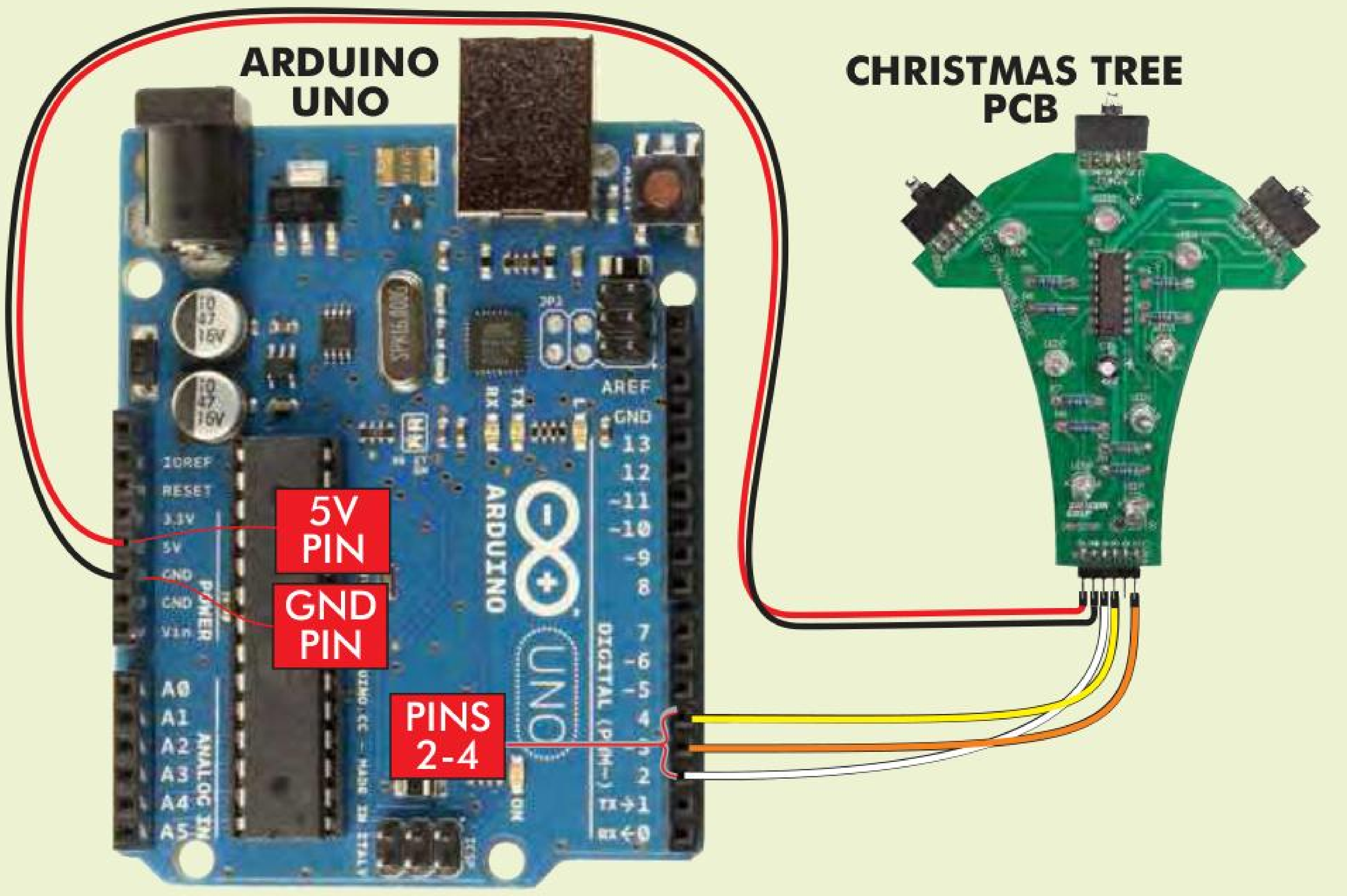
Next, select your board type and port from the Tools menu and upload the sketch to the board using the Upload button. You should then see the LEDs turn on one at a time, starting with LED1 and progressing to LED8.

If more than one LED turns on, or any LED does not light, something is wrong with your board. Check your wiring and soldering on the board. Also, check that the orientation of your LEDs is correct.

The sketch is designed to work with one board at a time but if other boards are connected, their LEDs should light up too.

You might notice that the LEDs on the other boards are delayed in comparison with the previous board. This is because the data from each board gets pushed onto the next board one cycle later.

We have also written another sketch which provides a random twinkle effect, ideal for simulating a Christmas tree (called **Stackable_LED_Tree_Twinkle.ino**) We've inserted plenty of comments in both programs to help you understand and customise them.



Here's an example of how the *LED Christmas Tree* PCB can be wired up to an Arduino board – we've used a Leonardo board and some plug-socket jumper wires here. The DO connection doesn't need to be connected, and is not used by any of the sample sketches.

If you haven't prepared that yet, you can use an Arduino programmed with the software described above. Once you are happy that the boards are working, you can start assembling them into a larger tree.

One from many

If you have built all your boards with headers, you just need to plug them all together. Note that as the tree gets larger, there are some sockets that you can't use, as the boards would overlap. You need to choose which one of the two conflicting boards you want to fit. Look at the opening page for an idea of how this can be done.

Once you have finished, any boards which have nothing plugged into CON1, CON2 or CON3 will need a jumper connecting pins 3 and 4. If you have not used sockets, bend a component lead off-cut into a 'U' shape, push it into the pin 3 and 4 pads for the relevant connector, solder it at both ends, then trim the excess lead.

If you are using sockets, you can use a small piece of tinned copper wire or component lead off-cut bent into a 'U' shape, as long as it is thick enough to stay firmly in the socket.

Or you can short out a two-pin header with a blob of solder (see photo opposite) and plug this into the middle of the socket.

We even created small pluggable jumpers by taking a two way piece of male header, and bridging the two sides with a ball of solder. This is handy if you want to experiment with your tree layout.

On the other hand, if you have very small kids around, it might be a good idea to use the option of permanently soldering the jumpers in place, as you don't want them to get loose and be swallowed!

By the way, if you want to be really creative, you could make several smaller trees and join them together using lengths of 6-way ribbon cable; there's no reason why the boards have to be in direct contact with each other, as long as CON4 on one board is wired to CON1, CON2 or CON3 on another board without transposing the connections.

Finally, depending on whether you want to connect your tree to an Arduino board or our dedicated controller, do see the instructions above or this issue's next article.

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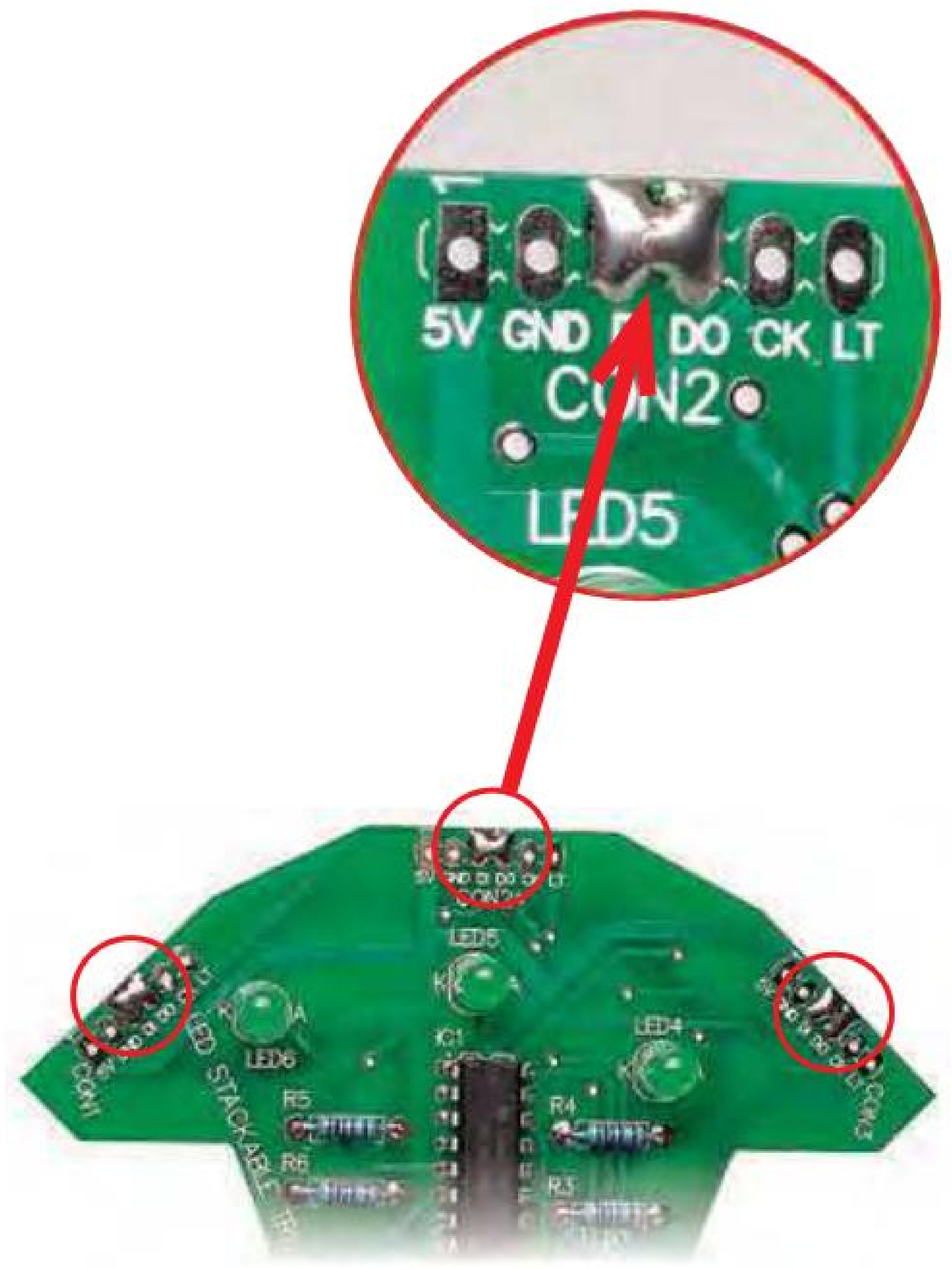

Any boards with nothing plugged into them need to have their DO and DI terminals shorted (in all three cases) – either with a soldered wire link or just with solder flowed between the pads.

We hope the Stackable *LED Christmas Tree* brightens up your Christmas and helps someone – perhaps your own little elves – learn a little electronics!

And by next Christmas you'll be wanting to make up a whole lot more add-on boards for a monster tree!

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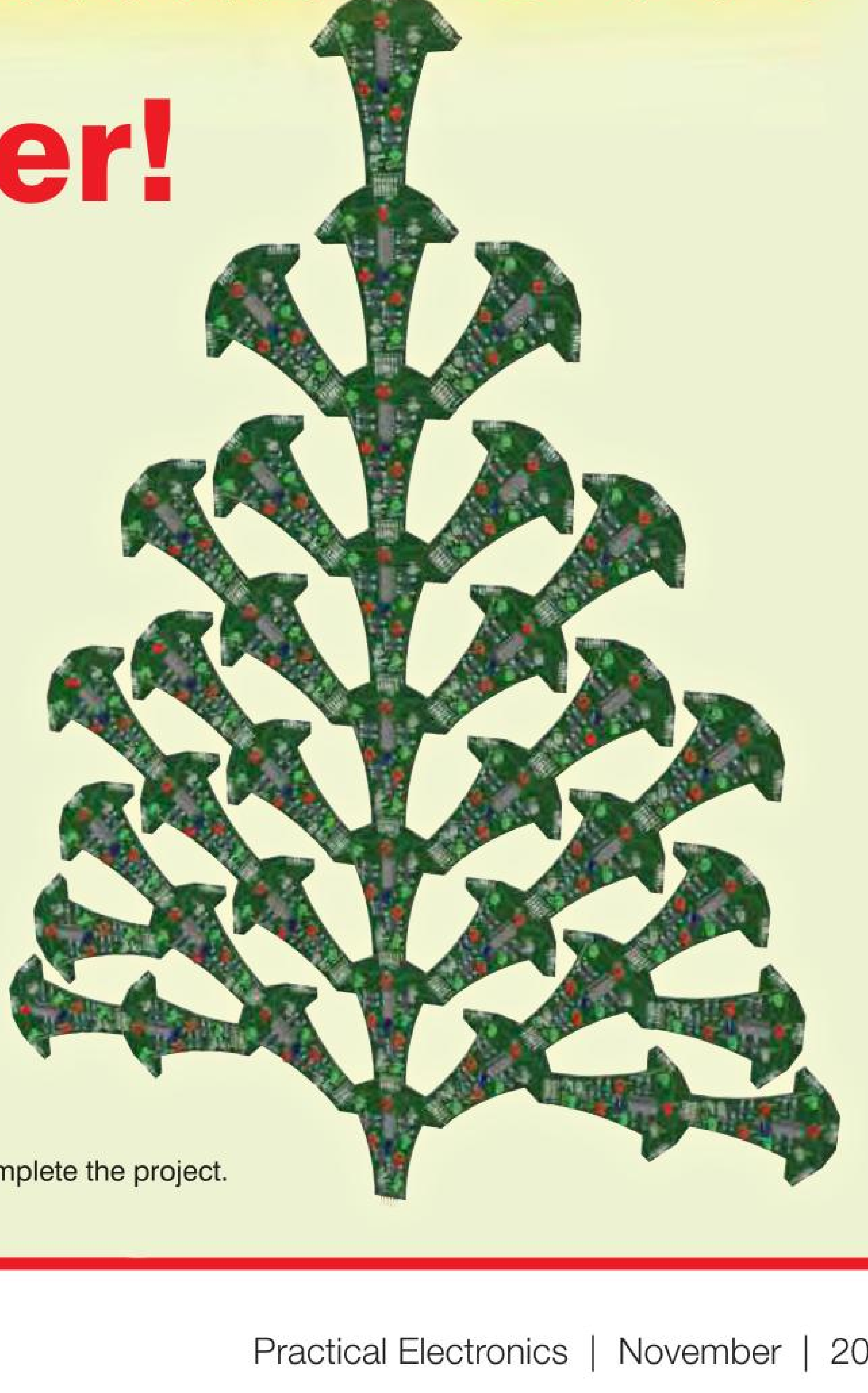

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USB Digital and SPI Interface Board

We originally designed this simple, low-cost interface to control the *LED Christmas Tree* elsewhere in this issue. But then we realised that with a minor tweak here, a slight adjustment there, we would have a general-purpose controller which could handle up to eight digital lines from your PC, including an SPI serial interface. So here it is: use it for the *LED Christmas Tree* or anything else that comes to mind!

by Tim Blythman

This small board uses a low-cost PIC16F1455 microcontroller, which incorporates a USB interface, to drive up to seven digital outputs and one input, including three used for SPI (serial peripheral interface) communications.

This means that you can use it to easily control some external circuitry from your PC.

The *LED Christmas Tree* earlier in this issue has an SPI-compatible interface and so it can be controlled using this board, but there are many other ICs which also use an SPI bus.

As a bonus, if the *Digital Interface Board* is powered up but not connected to a computer (say, it's connected to a USB phone charger) it will output random patterns to allow the *LED Christmas Tree* to be used without a computer.

So, if you want to develop a project around one of those ICs, this board would be a really easy way to experiment with such chips and test them out.

It can even be used to drive colour TFT LCD screens as many of these are based around an SPI interface, with the addition of a few digital control pins; this board can also drive those pins, using its four extra digital outputs.

You could also drive a standard alphanumeric LCD using this module. They typically require around 7 digital control pins; four for data and three for clocking/control.

Luckily, that's exactly what this board can provide. You can even use it to communicate over an I^{2}C interface.

It's based on a PIC

The PIC16F1455 used here is one of the smallest (and cheapest) PICs with a USB interface; and impressively, it only needs three other components to work.

You don't even need to solder a USB socket onto the PCB (although there is space to do so), as we've made the end of the PCB into a plug that will fit into a standard USB-A socket.

It isn't completely compliant with the USB specifications, but it's a technique that is quite widely used and it works fine.

Just keep in mind that the copper tracks can wear out if you're plugging and unplugging it a lot. In that case, a proper USB connector would be the way to go.

You might remember that the PIC16F1455 was used as the basis for the popular *Microbridge PIC Programmer and USB Serial Converter*, from the May 2018 issue.

The software we are using here is similar, in that it presents itself to the host computer as a serial port, but instead of producing a serial UART stream (compatible with RS-232), it generates an SPI stream instead.

What this means is that any program that can interface with a serial port on your computer can be used to control most SPI devices, including our stackable *LED Christmas Tree*. We've provided a sample program in the Python language to use with our *LED Christmas Tree*, but you can also use a terminal program such as the Arduino Serial Monitor to test out the commands and manually send SPI data.

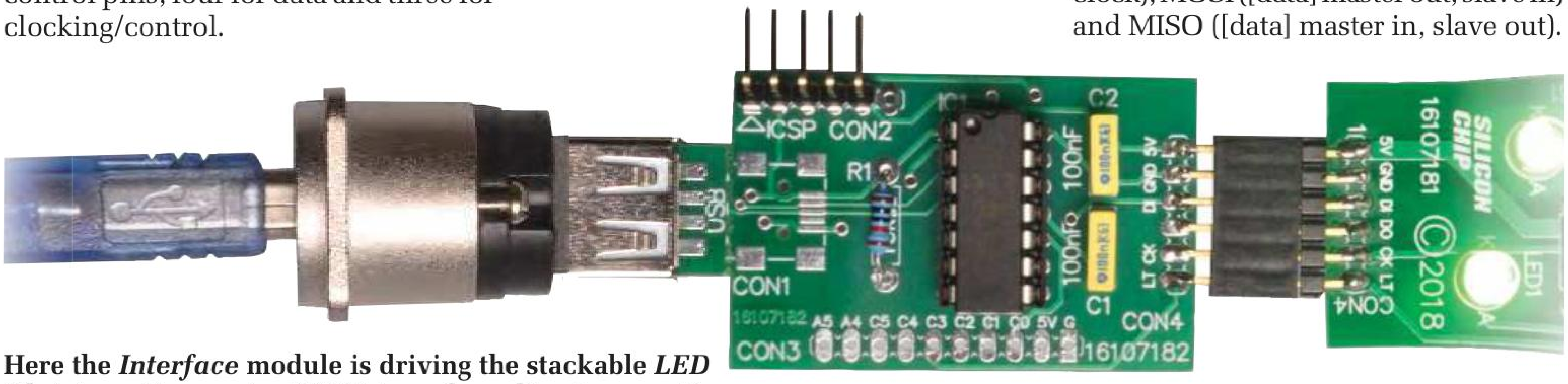
Two control modes

The way the *Digital Interface Board* works is as follows. If it is configured with a board rate of 9600, then the interface works in hexadecimal SPI mode. If the baud rate is set to 19,200, then it works in binary SPI mode. A baud rate of 38,400 selects I^{2}C mode (the data rate is 400kHz).

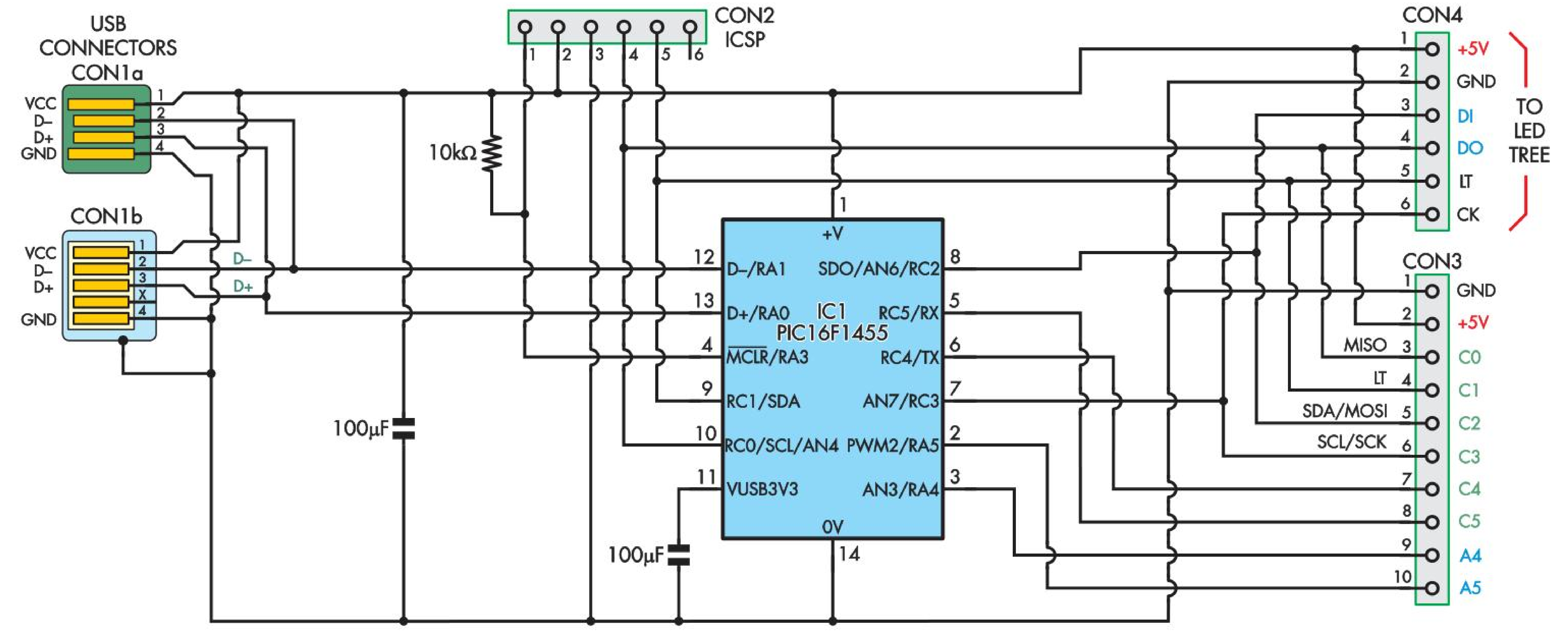
Note that these baud rates do not affect how fast the data is clocked out; they are just a convenient way of signalling to the *Digital Interface Board* which mode you want to use.

Hexadecimal SPI mode

Three of the seven digital output pins on the board can be used as an SPI serial bus. They are labelled SCK (the serial clock), MOSI ([data] master out, slave in) and MISO ([data] master in, slave out).



Here the *Interface* module is driving the stackable *LED Christmas Tree*, using CON4 to make a direct connection.



LED Tree Control Board

Fig.1: circuit diagram for the *Digital Interface Board*. IC1 is programmed to provide a USB interface via CON1, which can be either an SMD USB socket or tracks on the PCB which fit into a USB port. All of the PIC's free pins are wired to CON3 and CON4, to provide seven programmable digital outputs as well as an SPI or I^{2}C serial bus, to communicate with external circuitry.

In hexadecimal SPI mode, the unit accepts the hex digits 0-9 and A-F (and their lowercase equivalents) over the USB serial interface.

The letters T-Z and t-z are also accepted, as described below. Any hex digit received will cause four bits of SPI data to be transmitted on the MOSI and SCK pins, with the most-significant bit being sent first.

Any data that is received on the MISO pin (pin 10, RC0) is read back simultaneously with data being transmitted on MOSI. In this case, a hex digit is echoed back to the serial monitor.

The characters T-Z and t-z can be used to set the state of the pins directly, with the uppercase character setting the pin to high and the lowercase character setting the pin low – see Table1 below.

This feature is used with the *LED Christmas Tree* to latch the data when required. Any other characters received over the USB interface are ignored.

For example, using the hexadecimal mode, we can turn off all the LEDs on a single board of the *LED Christmas Tree* by sending the string 'v00V'. This brings pin 9 low, then sends eight bits of zeros over the SPI bus, then brings pin 9 high, transferring the shifted data into the device's output latches. Similarly, sending the string 'vFFV' will turn all the LEDs on.

Because other characters are ignored, line endings don't matter and practically any terminal program can be used to send this data.

Note that there are only seven pins listed in Table1 because the eighth pin, pin 10, is only used as an input and only in SPI mode.

Binary SPI mode

In binary SPI mode, we take advantage of the fact that USB data is sent in packets. Each time the *Digital Interface Board* receives a packet from the host, it sets LT low, clocks out the data using SCK and MOSI and then sets LT high again. It also reports serial data received on the MISO pin back to the host in binary format.

Table1: pin connections and control characters

Control characters	IC1 pin pin	CON3 pin	CON4 pin
t/T	3 (RA4)	9	–
u/U	2 (RA5)	10	–
(input only)	10 (RC0, MISO/DO)	3	4
v/V	9 (RC1, LT)	4	5
w/W	8 (RC2, MOSI/DI/SDA)	5	3
x/X	7 (RC3, SCK/CK/SCL)	6	6
y/Y	6 (RC4)	7	–
z/Z	5 (RC5)	8	–

While this mode provides faster communications, it can only be used with a host terminal program that sends multiple bytes together, so that the data is received by the unit as a single packet.

This is possible with the Arduino Serial Monitor, provided that line endings are turned off, as these will otherwise appear as binary data to the unit.

If you are driving an *LED Christmas Tree* board in binary mode and see LED2 and LED4 on when you are not expecting them to be on, that indicates that you may have line endings still turned on, as this combination corresponds to the character that is used to terminate a line (line feed [LF], binary 00001010, ASCII code 10).

While trickier to use manually, this mode is more convenient for writing software which delivers data to the serial port directly.

Hexadecimal I^{2}C mode

To make this board even more flexible, we have also added an I^{2}C mode. In this mode, RC2 is used as SDA while RC3 is used as SCL.

To use it, you write one or more bytes to the serial port in hex format (ie, pairs of characters 0-9 or A-F), followed by a 'newline'. When the newline character is received, the previous bytes are transmitted over the I^{2}C bus.

Alternatively, you can prefix the bytes with 'S' to start communication and follow with 'P' to finish.

The first byte contains the 7-bit device address plus one bit to indicate read or write mode. The board scans this byte to determine whether you are doing a read or write and acts accordingly.

Each byte read is followed with a 'K' to indicate if an ACK signal was received or an 'N' if it did not receive the ACK. In read mode, after the initial address byte, you simply send 'FF' for each byte you wish to read back. The response will then be read back and displayed along with the ACK/NACK indicators mentioned earlier.

The *Digital Interface Board* also supports 10-bit addressing mode. In this mode, the top five bits

Parts list – USB/SPI Interface Board

- 1 double-sided PCB coded 16107182, 55mm x 28mm availabel from the PE PCB Service
- 1 PIC16F1455-I/P microcontroller programmed with 1610718A.HEX (IC1)
- 1 14-pin DIL IC socket (optional, for IC1)
- 1 mini USB type B SMD socket (CON1b; optional)
- 1 5-way right-angle (or straight) pin header (CON2, ICSP; optional)
- 1 10-way pin header or socket (CON3)
- 1 6-way female header socket (CON4)
- 2 100nF MKT capacitors
- 1 10kΩ 1% or 5% resistor, 1/4W or 1/2W

of the address byte are 11110, and a second address byte follows. It will detect this and act accordingly.

The clock rate for I^{2}C mode is always 400kHz. (Note: there are no I^{2}C bus pull-up resistors on the board. If your slave lacks pull-ups you'll need to fit some.)

Check the I^{2}C specifications to determine the correct pull-up resistors to use for your circuit.

Circuit description

The circuit of the *Digital Interface Board* is shown in Fig.1. A 10kΩ pull-up resistor from pin 4 ($\overline{\text{MCLR}}$) of IC1 to VCC enables the power-on reset feature and allows for normal operation of the chip after power is applied.

One 100nF capacitor between VDD (pin 1) and VSS (pin 14) provides overall supply bypassing, while another capacitor from pin 11 (VUSB3V3) to ground filters the internally generated USB 3.3V supply.

The proper USB socket and PCB track socket are wired in parallel, with the D– and D+ signal lines going to pins 12 and 13 of IC1 respectively. The software sets these pins to operate as USB signal lines rather than general purpose I/O pins.

An optional six-pin header for in-circuit serial programming (ICSP) is provided (CON2), to allow IC1 to be programmed in situ. If you're using a pre-programmed chip, you can leave CON2 off the board.

Finally, CON3 and CON4 break out the digital I/O pins. 10-pin header CON3 provides connections to GND (0V) and the USB 5V rail, as well as the eight I/Os that the unit can control (RC0-RC5 and RA4-RA5).

By comparison, 6-pin header CON4 only includes the four signal connections which are required for SPI or I^{2}C communications, along with the GND and 5V connections.

This suits the *LED Christmas Tree* board, which can be plugged straight into this header. But it could also be used in any other situation where you just need to communicate with an SPI or I^{2}C device.

As mentioned earlier, the RC0 pin on IC1 is used as an input only, in SPI mode, while the other seven pins are digital outputs. Outputs RC2 and RC3 can be used for either SPI or I^{2}C serial communications, or as general purpose I/Os.

Construction

Use the PCB overlay diagram (Fig.2) as a guide during constructions. The *USB Digital and SPI Interface Board* is built on a PCB coded 16107182, which measures 55 x 28mm and is available from the *PE PCB Service*.

If you intend to install the optional USB socket, we recommend doing that first, before any other components are in the way. To do this, the USB projection on the PCB needs to be snapped or cut off; otherwise, it would foul the cable.

First, score along the line of 'mouse bites' to help the PCB break cleanly. This will also help to sever the PCB traces so that they don't tear when the board comes apart. Flex the board at the score line and it should snap. Clean up any rough edges with a file.

The USB socket is the only SMD component used. We recommend that you put a thin smear of flux paste on the pads before soldering.

The socket has plastic pegs on its underside to locate it on the PCB. Once positioned, ensure it is flat and solder the large mechanical tabs on the sides to lock it in place.

With a clean, fine tip loaded with a bit of extra solder, carefully apply the iron to the pins and pads. The flux should draw the solder up and onto the pins. Solder all the pins and inspect them to ensure there are no bridges between adjacent pads. If there are bridges, remove them with some additional flux paste and a piece of desoldering braid (solder wick).

Required components

There is just one resistor on the board, so solder that in place next. Follow with the two identical capacitors. None of these components are polarised.

If you are using an IC socket for IC1 (which is recommedned if you plan to use an external programmer), fit it next, ensuring the notch is facing towards the top of the board, as shown in Fig.2.

If you will be plugging CON4 into a stackable *LED Christmas Tree* board, you should ensure that it will line up nicely before soldering it.

Programming the PIC

If you have a blank PIC, you can program it using a PICkit 3 or PICkit 4, in conjunction with the MPLAB X IPE (Integrated Programming Environment) software. This is bundled with the MPLAB X IDE (Integrated Development Environment), which can be downloaded from: **https://www.microchip.com/mplab/mplab-x-ide**

Having installed it, launch the IPE program. From the Setting Menu, select Advanced Mode and log in using the default password. Click the Power button on the left and ensure 'Power Target Circuit from Tool' is ticked.

Click the Operate button and select PIC16F1455 from the Device list, select your programmer from the Tool list and click Connect.

Once it indicates success, use the Browse button to select a source HEX file and open the HEX file from the software download file.

Connect the programmer to the PCB, ensuring that the arrowed pin on the programmer lines up with pin 1 (arrowed) on the PCB. Click the Program button and check that the messages in the bottom of the window indicate that IC1 was successfully programmed.

To test the chip, unplug the programmer and connect the board to a USB socket. Your computer should show that a new USB serial port has been detected.

We suggest that you solder one pin in place and then check the alignment is correct before soldering the rest.

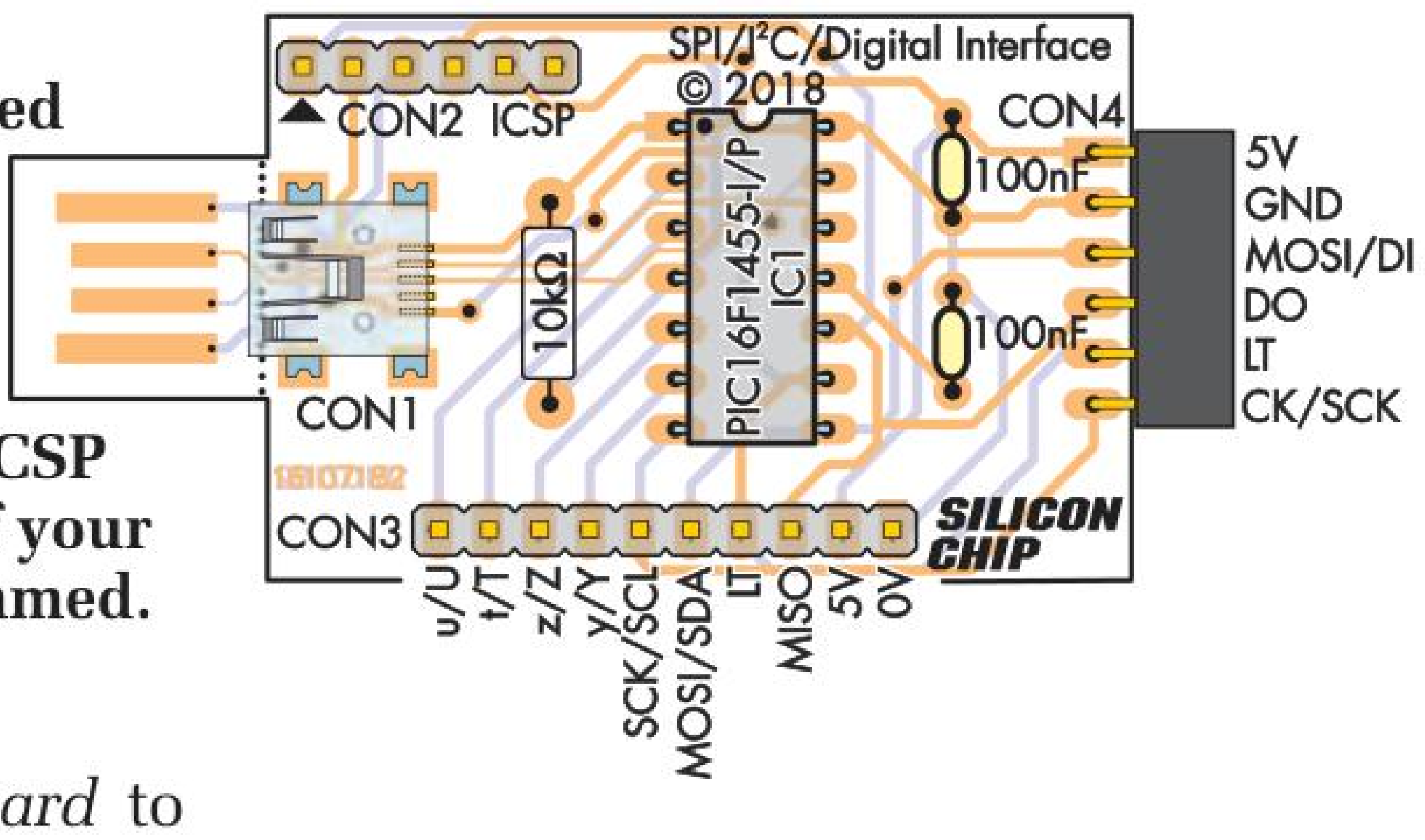
You don't need to fit CON2 if you have purchased a pre-programmed PIC. But note that even if you will be using it to program IC1, you can plug it in and hold it in place while programming the chip, then remove it.

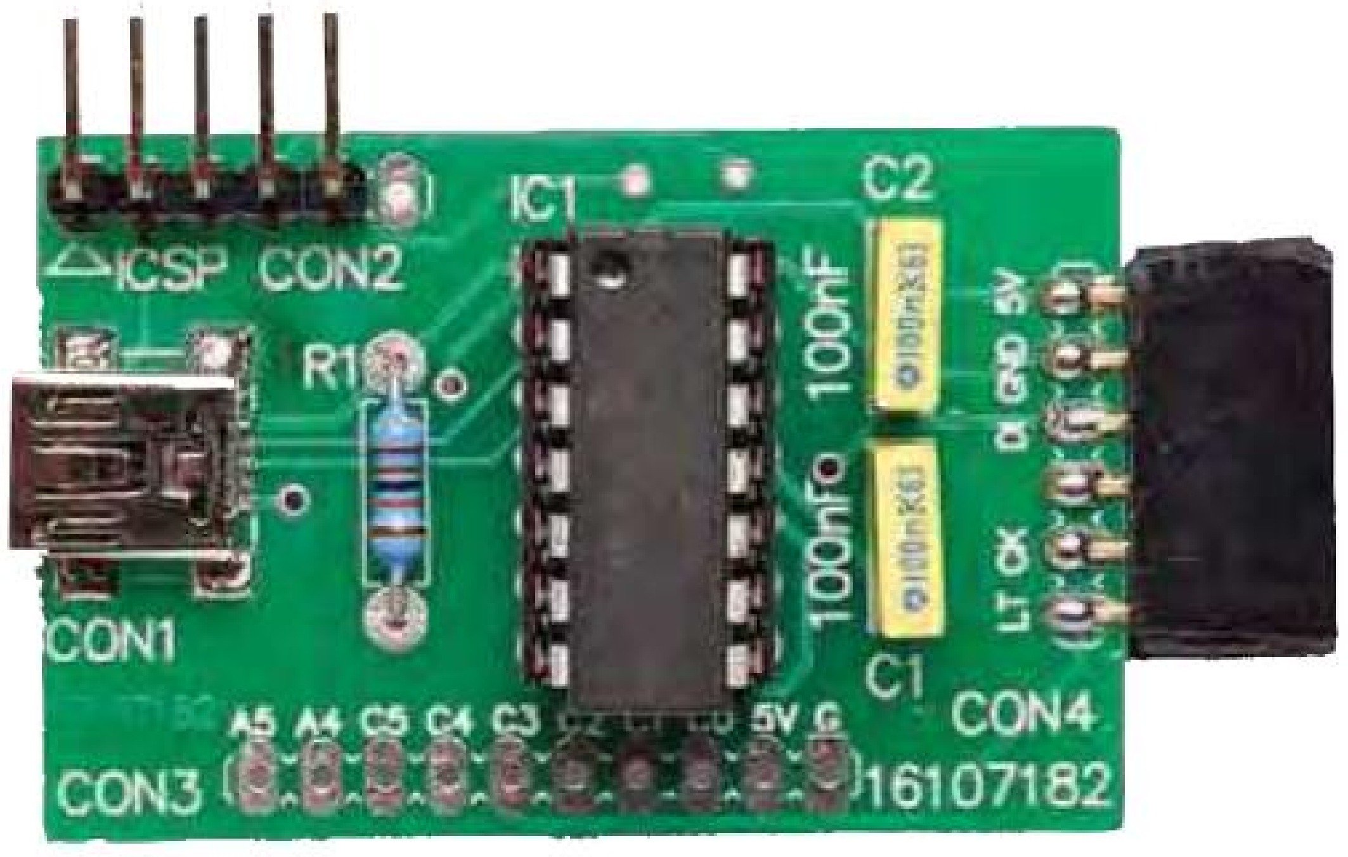
If you are programming IC1 using an external programmer, do so now (see the above panel for instructions), then plug the programmed chip into the socket.

Or, if you're not using a socket, solder it to the board now but make sure it is oriented correctly first.

Enlargement of the USB 'plug' section of the PCB, which is removed if a micro USB socket is used (as shown opposite, above). Score along the 'mouse bite' holes before snapping this section off and clean the edge with a file.

Fig.2: it doesn't get much easier than this. IC1 is the only polarised component; make sure to fit it with the orientation shown here. You can use a socket if you don't want to solder the chip directly to the board. The ICSP header (CON2) is not required if your micro has already been programmed.





The simplest connection method is to plug the PCB straight into a USB port, but if you fit a socket as shown here, the result is a bit more robust. It also makes the board slightly more compact.

Using it

To use the *Digital Interface Board* to drive the stackable *LED Christmas Tree*, plug the root board of the tree into the six-way socket on the *Digital Interface Board*, with both boards facing up so that the pin names match.

Plug the *Interface Board* into a USB port on your computer and open a terminal program such as the Arduino Serial Monitor, PuTTY or TeraTerm. Select a baud rate of 9600 (usually the default).

Type 'vFFV' into the terminal and press Enter. All the LEDs should light up on the root board, indicating that it's all working properly. Typing 'v00V' and pressing enter should cause all the LEDs on the root board to switch off.

If your tree has multiple boards, use a longer string such as 'vFFFFFFV' (which suits three boards). Each hex digit corresponds to four LEDs, so you will need two hex digits for each board in the tree. If you don't supply enough hex digits, the furthest downstream boards will be fed old data from other upstream boards.

To use this board to drive a different SPI or I^{2}C device, refer to Table 1 to find which connections on your device need to go to which pin on CON3 or CON4. You then set the baud rate to any of those mentioned under the 'Two control modes' cross-heading above and use a terminal program as described to send test commands and check responses.

It's much easier to use the hexadecimal control modes initially to test the unit out, even if you're planning on using the binary SPI mode later.

Python program

We have provided a small example script written in the Python programming language to drive the *LED Christmas Tree* using this *Interface Board*. You will need some Python experience (or at least some script programming experience) to modify it. (The Python language can be downloaded (**www.python.org/downloads/**). You will also need the pyserial library to access the serial port. This can be added by running the following from the Python command line:

```
pip install pyserial
```

Download the program, **Serial Tree.py**, from the November 2020 page of the *PE* website and change the port name to suit your system (eg COMx on windows, /dev/ttySx on Mac/Linux), and then run the program using the Python interpreter. It generates random patterns to give a twinkling effect.

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Tektronix 2430A	Oscilloscope Dual Trace 150MHz 100MS/s	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHz	£600
Farnell AP60/50	PSU 0-60V 0-50A 1kW Switch Mode	£300
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell AP100-90	Power Supply 100V 90A	£900
Farnell LF1	Sine/Sq Oscillator 10Hz – 1MHz	£45
Racal 1991	Counter/Timer 160MHz 9 Digit	£150
Racal 2101	Counter 20GHz LED	£295
Racal 9300	True RMS Millivoltmeter 5Hz – 20MHz etc	£45
Racal 9300B	As 9300	£75
Solartron 7150/PLUS	6½ Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHz – 20kHz	£600
Solartron SI 1255	HF Frequency Response Analyser	POA
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160 – £200
Thurlby TG210	Function Generator 0.002-2MHz TTL etc Kenwood Badged	£65

HP/Agilent HP 34401A Digital
Multimeter 6½ Digit £325 – £375

HP33120A	Function Generator 100 microHz – 15MHz	£350
HP53131A	Universal Counter 3GHz Boxed unused	£600
HP53131A	Universal Counter 225MHz	£350
Audio Precision	SYS2712 Audio Analyser – in original box	POA
Datron 4708	Autocal Multifunction Standard	POA
Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

Marconi 2955B Radio
Communications Test Set – £800

HIGH-POWER 45V/8A VARIABLE LINEAR SUPPLY

SILICON CHIP
45V
8.0A
TRIP
SET: 45.8V 8.20A
20°C 45.8V 0.02A
LOAD ON
SET VOLTAGE
CURRENT
Variable DC Power Supply

Last month, we introduced our new *Linear Bench Supply*, capable of delivering 8A at 45V or 2A at 50V. It's based around a 500VA toroidal transformer, a PCB control module fitted to a finned heatsink and two thermally controlled fans to keep it cool. These all mount in a metal instrument case. This month, we cover the assembly and testing details of the PCB module.

Part 2

by Tim Blythman

There are quite a few steps involved in building this *Linear Bench Supply*, but none are terribly complicated. So if you follow our instructions, you shouldn't have any trouble getting it to work and ensuring that it's safe.

You'll need most or all of the parts in the list at the end of this article, so the first job is to gather those.

There's a bit of screwing, drilling, tapping and cutting needed to complete the hardware side of this project. Ideally, you should have a drill press, although you can get away with a decent hand drill.

You'll also need assorted drill bits, an M3 tap set, files and a hacksaw on hand.

Around half of the assembly time is in building the control module, with the other half preparing the case and putting it all together. We'll have the case assembly and wiring details next month. This month's article concentrates on building that control module.

We've made it as easy as possible by using almost entirely through-hole components and mounting them all on a single PCB. So let's get started building it.

Construction

Before mounting any parts on the control board, use the blank PCB and some of the other parts to mark out where holes will need to be drilled on the heatsink. The hole locations are shown in Fig.5, but it's better to use the actual PCB and devices to determine where to drill.

Start by fitting the PCB with the 9mm tapped spacers at each corner. Then temporarily place transistors Q3, Q4, Q5, Q6, Q7 and REG3 into their respective mounting holes, but don't solder them yet.

Place the acrylic spacer under the heatsink to lift it up by 3mm, then centre the PCB on the face of the heatsink.

Make sure that each component is sitting up straight and at the same height, then mark where the centre of each mounting hole sits on the heatsink (eg, using a felt tip pen).

Hold the bridge rectifier in place above the main devices, centred on the heatsink (see photos) and mark its mounting hole too.

While you're at it, use the acrylic insulating plate to mark out the positions of the four mounting holes on the underside of the heatsink, two on each side.

Now take the heatsink away and carefully drill all the marked holes with a 2.5mm bit to a depth of at least 6mm (or deeper if you don't have an M3 finishing/bottoming tap), making sure they are drilled perpendicular to the face of the heatsink. Use light machine oil to lubricate the drill bit and regularly clean out swarf.

Once all the holes have been drilled, tap them for an M3 thread to a depth of at least 6mm, again using plenty of lubricant and regularly clearing swarf from the tap.

Be careful not to use too much force to turn the tap, or you could break it, ruining both it and the heatsink.

As long as you regularly remove the swarf and re-lubricate the tap and hole, a consistently moderate amount of torque should be required.

If you do encounter increased resistance, unwind the tap a little bit and then try winding it clockwise again. If the resistance is still there, take it out and clean and re-lubricate the hole, then try again.

You can use a finishing tap to get the tapped holes to the required depth, or drill them a bit deeper and use the intermediate tap to cut threads at least 6mm into each hole. When finished, deburr all the holes and clean out all the swarf.

You may like to wash the heatsink with soapy water and let it dry off to get rid of the lubricating oil and any remaining swarf.

Before proceeding, it's also a good idea to use the bare PCB to mark out where its mounting holes will go in the bottom of the case.

Use the heatsink acrylic spacer to do the same for the four heatsink mounting holes, and position the mains transformer as shown in the photos, to mark out its central mounting hole.

Make sure you leave enough space behind the heatsink fins for the fans. The fins should be around 45mm from the inside rear of the case.

PCB assembly

With that out of the way, we can now proceed to assemble the PCB using the overlay diagram (Fig.6) as a guide.

The *Linear Bench Supply* is built on double-sided PCB coded 18111181, measuring 150 × 120mm and available from the *PE PCB Service*. The following description assumes the PCB is oriented as shown in Fig.6, with the heatsink-mounted devices at the bottom edge.

There are two surface-mounted parts on this PCB, which should be fitted first. These are the 15mΩ shunt resistor and shunt monitor IC4, in an 8-pin SOIC package, which is mounted near the shunt.

Start with IC4. Apply flux paste to its pads, then locate IC4 over them. Make sure that its pin 1 is oriented so that it's closest to the shunt pads. Pin 1 is typically marked with a dot or divot on top of the IC package and a bevelled edge on that side.

Once it is in the correct location, solder one of its pins. Check that all of its pins are lined up with their pads. If not, re-heat the solder joint and gently nudge the part into place with tweezers.

Once you are happy that the part is aligned and flat against the PCB, solder the remaining pins by applying some solder to the iron tip and carefully touching each pin in turn. The solder should flow from the iron to the pin. Once the other pins are soldered, go back and re-touch the first pin.

If you are having trouble, apply some more flux. Excess solder can be removed with solder wick and a bit of extra flux paste. If a bridge occurs, don't remove it right away, but solder any unsoldered pins first. Then use the wick on one side at a time to remove any bridges.

The shunt is the next part to be fitted. It is relatively easy to solder but is connected to a wide power trace, so it may need a bit more heat. The shunt is not polarised.

It's a good idea to use an unassembled PCB and the acrylic heatsink spacer as a template to mark the mounting hole positions inside the case bottom. It's easier to do this now, rather than later!

Apply solder to one pad, then rest the part on top and apply heat again to allow the part to sink into the solder and down onto the pad (pressing down on the part with tweezers helps with this process). When the first solder joint is good, solder the other side, then go back and re-touch the first joint.

With these two parts in place, it's a good idea to clean up any excess flux on the PCB using isopropyl alcohol or a specialised flux remover.

Through-hole parts

You can now fit all the smaller axial parts, ie, resistors under 1W, zener diode ZD1 and small signal diodes D1-D4. Make sure that the diodes are oriented as shown in the overlay diagram.

While the resistors have colour-coded bands, these can be hard to distinguish, so it's best to check each with a multimeter set to measure ohms before soldering them in place.

Next, fit the six 1W resistors and the two larger diodes (D5 and D6), again ensuring their cathode stripes are facing in the directions shown in Fig.6. Watch out – they're oriented differently.

The next job is to fit DIP ICs IC1-IC3, IC5 and IC6. These are all LM358 op amps except for IC3, which is a 555 timer.

You don't need to use sockets; in fact, it's better to solder these all directly to the PCB. But make sure that in each case, the pin 1 dot/notch is facing as shown in the overlay diagram and the IC is pushed down fully onto the board before soldering all of its pins.

The next components to mount are the MKT and ceramic capacitors. The MKT capacitors are mostly 100nF in value, although one is 1nF so don't get them mixed up. The location for each capacitor is shown in Fig.6.

You can now solder the seven BC546 transistors in place, along with REG5. The transistors and regulator look similar, so don't get them mixed up. You may need to bend their leads out with small pliers to fit the PCB pad patterns.

Next, mount DIL pin header CON6, followed by the trimpots. Orient them so that the adjustment screws are positioned as shown in the overlay diagram. They are all the same value.

Follow with the two 5W resistors, which can be installed slightly above the PCB surface to improve convective cooling, although this is not critical.

Note that, as explained last month, you may need to change the value of the 33Ω 5W resistor if you're using different fans from the ones specified (which we don't recommend!).

Now fit the terminal block (CON1), with its wire entry holes facing the edge of the board, and polarised

Fig.5: a half-size drilling template for the heatsink. All holes are drilled and tapped for an M3 thread, to a depth of at least 6mm. While this should give you an idea of what to expect, as mentioned in the text, it's better to temporarily insert the actual devices and mark where their mounting holes sit if possible.

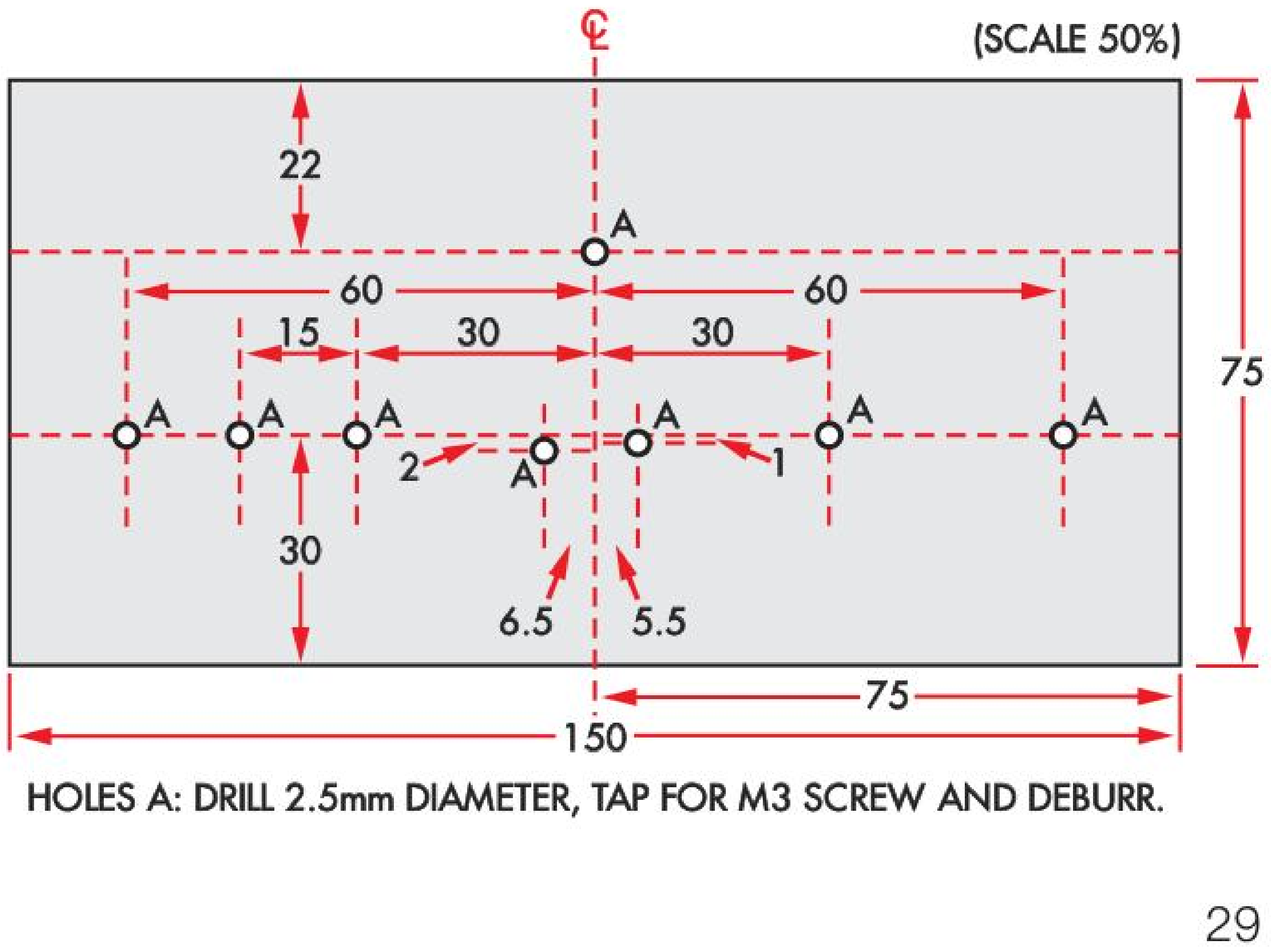
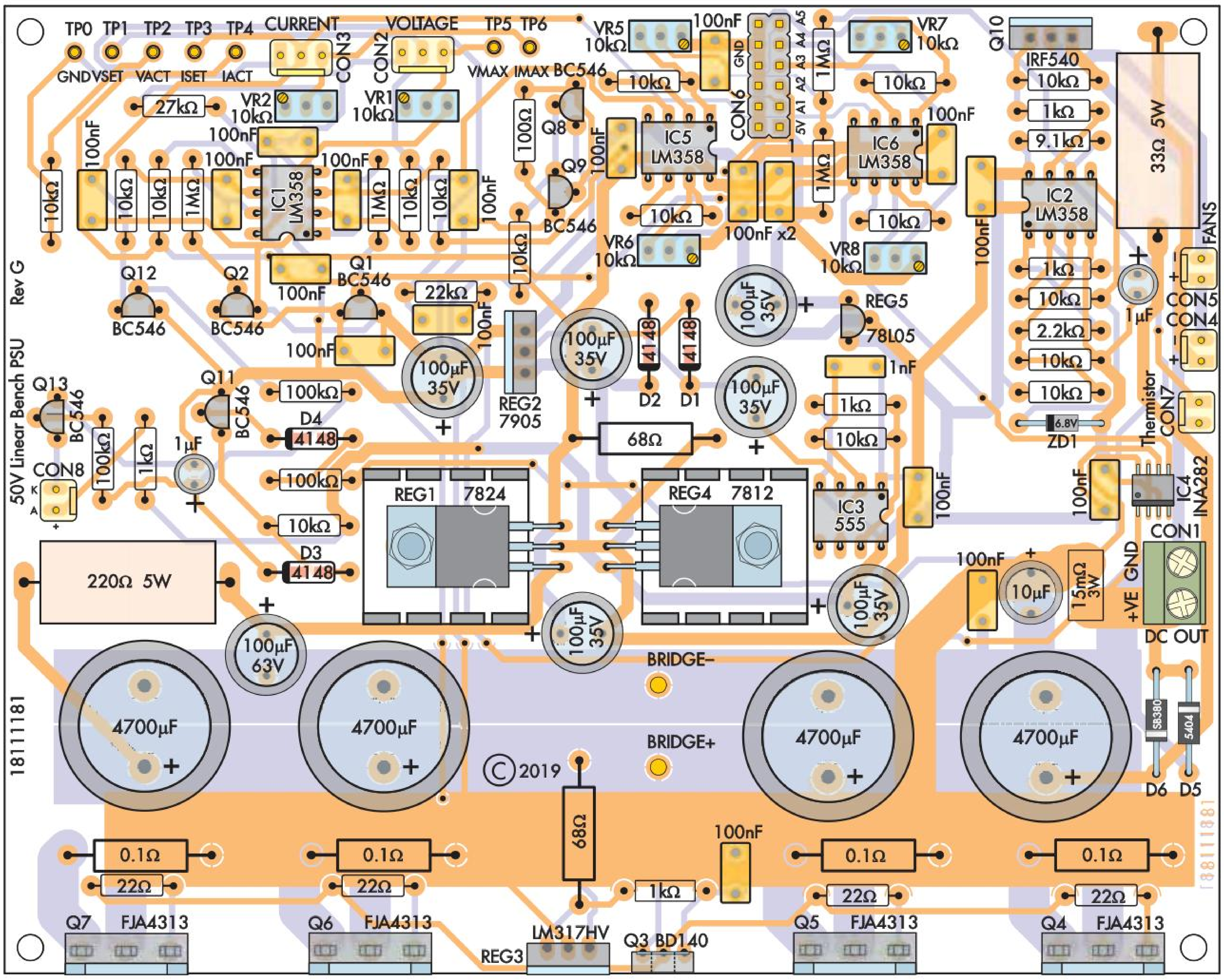


Fig.6: most of the *Linear Bench Supply* components mount on this control board. Ensure that the diodes, transistors, ICs and electrolytic capacitors are fitted with the correct orientations as shown. It's also a good idea to check carefully that the different value resistors and capacitors go in the right places. Note that one of the 100µF electros is rated at 63V (below and to the right of the 220Ω 5W resistor) where all others are 35V. Fit the four 4700µF capacitors last, after the power devices (that mount on the heatsink along with the bridge rectifier) have been soldered in place.


TP0 TP1 TP2 TP3 TP4 CURRENT VOLTAGE TP5 TP6
GND VSET VACT ISET IACT
CON3 CON2
VMAX IMAX
VR5 10kΩ
VR7 10kΩ
Q10 IRF540
VR2 10kΩ
VR1 10kΩ
27kΩ
100nF
BC546 Q8 Q9
IC5 LM358
CON6
GND A5 A4 A3 A2 A1 5V
1MΩ
IC6 LM358
IC1 LM358
IC2 LM358
33Ω 5W
9.1kΩ
1kΩ
10kΩ
100Ω
VR6 10kΩ
VR8 10kΩ
100nF x2
FANS
CON5 CON4
Q12 Q2 Q1
BC546
22kΩ
100µF 35V
REG5 78L05
1nF
1µF
2.2kΩ
Rev G
50V Linear Bench PSU
Q13 Q11
REG2 7905
4148
D2 D1
D4 D3
100kΩ
68Ω
6.8V ZD1
Thermistor CON7
CON8 K A
REG1 7824
REG4 7812
IC3 555
IC4 INA282
CON1
GND +VE
220Ω 5W
100µF 63V
10µF
15mΩ 3W
DC OUT
BRIDGE−
BRIDGE+
4700µF
18111181
© 2019
SB380 5404
D6 D5
0.1Ω
22Ω
1kΩ
Q7 FJA4313
Q6 FJA4313
LM317HV REG3
Q3 BD140
Q5 FJA4313
Q4 FJA4313

headers CON2-CON5, CON7 and CON8. The polarised headers should be mounted with the orientations shown in Fig.6.

Onboard regulators

REG1 (7824) and REG4 (7812) both need flag heatsinks as REG1 drops around 20V and REG2 drops 8V. Both are mounted identically but rotated 180° relative to each other.

Start by lining up the component with its footprint to determine where the leads need to be bent down by 90°. Having bent the leads, check that the tab mounting hole lines up with them inserted. If not, adjust the bend.

When you are happy with this, smear a small amount of thermal compound on the back of the regulator and mount it by sandwiching the flag heatsink between the regulator and the PCB.

Fasten with a 6mm machine screw from the bottom and a nut on the top of the tab. Ensure the nut is tight but be careful not to twist the regulator and its leads.

Ensure the regulator and heatsink are square within their footprints and not touching any other components before soldering and trimming their leads.

You can fit most of the electrolytic capacitors next; all but the four large 4700µF units. They are polarised; in each case, the longer (positive) lead must be soldered to the pad marked with a '+' on the PCB. The cans have stripes on the opposite (negative) side.

Follow with the two remaining onboard TO-220 components, REG2 and Q10. These do not need heatsinks as their dissipation is quite low. They can be fitted vertically, but make sure that their tabs are facing as shown in Fig.6.

Connecting the off-board components

Assuming that you are using the *Five-way Panel Meter* module for display, you will need to build that separately (see the article starting on page 36). If you're using individual panel meters, we'll leave that part of the construction up to you. Most of the work is in cutting holes for them in the front panel and wiring them up.

Voltage and current adjustment potentiometers VR3 and VR4 mount on the front panel and connect to the PCB using flying leads and polarised plugs. This prevents them from being accidentally connected backwards if the unit is later disassembled.

Separate a 150mm length of 10-way ribbon cable into two three-way pieces and three two-way pieces. Trim the two three-way pieces to around 10cm each, separate the wires at each end, strip them and solder one end of each to the leads of VR3 and VR4. You may wish to protect the solder joints with short pieces of small-diameter heatshrink tubing.

Now crimp the polarised plug pins onto the other ends of the wire. If you don't have the correct tool, it may be easier to solder the wires, although the tabs of the pins will still need to be bent over to fit into the housing.

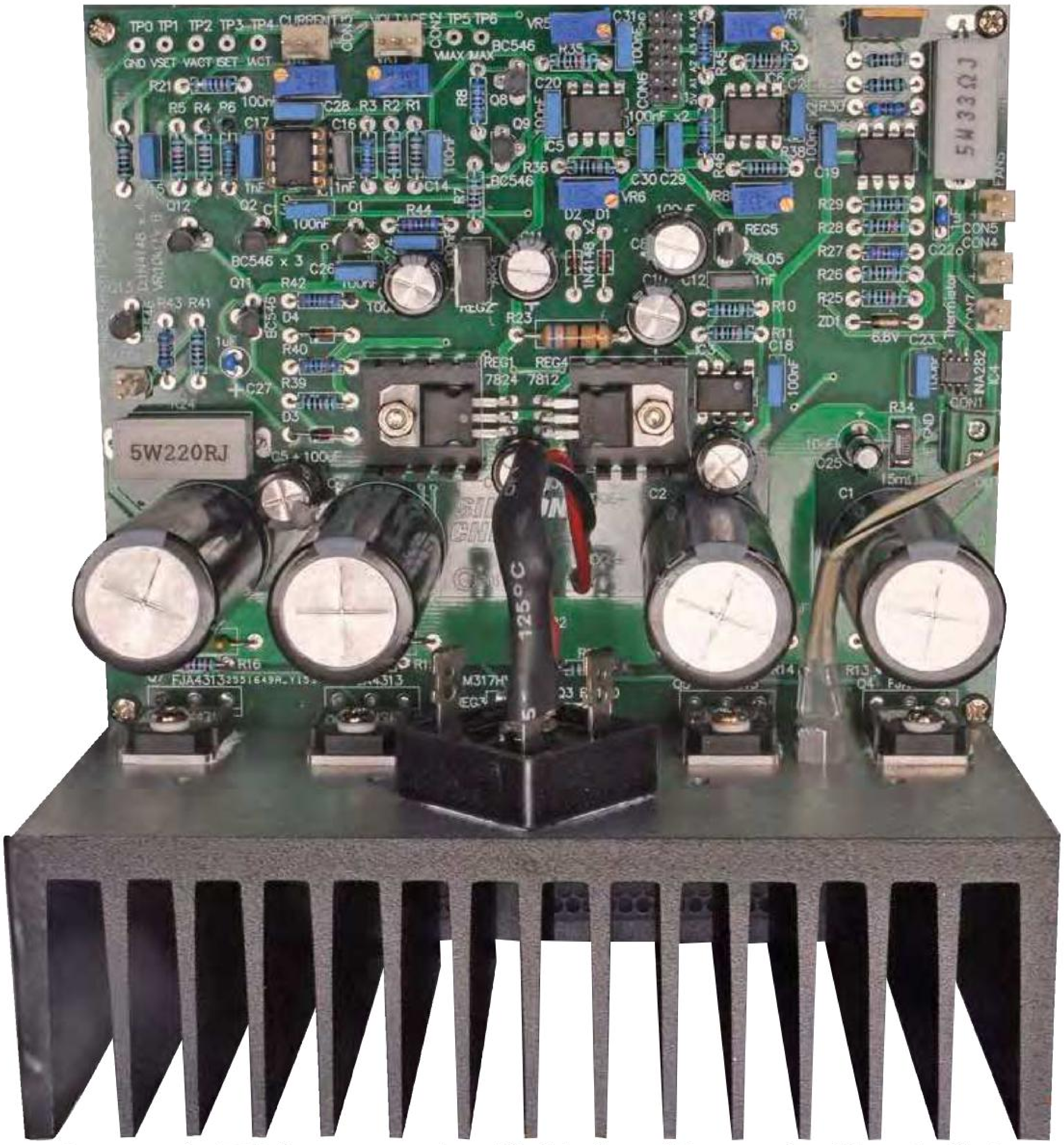
You can crimp them using small pliers in a pinch (no pun intended), but it's a bit tricky. These will plug into CON2 and CON3.

The square pads of CON2 and CON3 are connected to ground, so should go to the ends of the potentiometer tracks which have a low resistance to the wipers with the pots fully anti-clockwise. The middle connections of CON2 and CON3 go to the wipers, and the third pin goes to the other end of the tracks.

You can check this by verifying that, with the pot cables plugged into the board, the middle pins have a low resistance to ground (TP0) when the relevant knob is wound fully anti-clockwise. If this is not the case, you may have the outside leads reversed.

LED1 is also attached using flying leads and mounted off the PCB, via CON8. Solder a length of the two-way ribbon cable to the pins for a matching polarised plug, then solder the other ends of the wire to the LED. The longer lead of the LED must be soldered to the wire that goes to the pad on CON8 marked with a plus sign.

If using a pre-wired panel-mount LED, simply crimp or solder the wires to the plug pins and push them into



Compare the PCB layout opposite with this shot of the completed board, albeit with its transistors (and bridge) already fixed to the heatsink

the housing. If you have a bare LED, you should heatshrink the wires to insulate and protect them, and use a bezel for mounting.

If your fans are not already terminated with 2.54mm-pitch headers, attach a keyed plug as for the LED. Note that the positive lead for both fans (ordinarily red) goes to the pin closest to output connector CON1.

A similar header is used to connect the NTC thermistor for monitoring the heatsink temperature. It is not polarised like the other components, but you can still fit the same style plug to connect to the locking header on the PCB, so do that now.

The bridge rectifier (BR1) is mounted on the heatsink and connected to the transformer and PCB via four stout (10A-rated) wires. Cut two wires around 7cm long and crimp or solder spade terminals to one end of each. Protect the outside of the spade using heatshrink tubing insulation.

Solder the other end of the wires to the PCB. The red wire should go to the terminal marked BRIDGE+ (and the bridge rectifier terminal with a plus) and the black wire to the terminal marked BRIDGE– (and the diagonally opposite bridge rectifier terminal).

Initial testing

Now detach all the external components except for the two potentiometers, VR3 and VR4, and the NTC thermistor. This will allow you to do some basic checks.

Before powering the board up, double-check the construction so far, making sure that all the onboard components have been fitted, with the correct polarity. Check also that the solder joints all have good fillets, do not look dry and that there are no shorts between solder joints on the underside of the board.

The initial tests are only made at low power, but there is still enough energy present to damage components if something has been installed incorrectly. There is the possibility of components becoming very hot if a fault occurs, hence the initial low-power tests which should hopefully find any problems before delivering enough energy to do any damage.

Note that there can be 70V differential voltage between various parts of the circuit when it is powered on. This is enough to give a shock. Make sure the PCB is mounted on insulated tapped spacers and there is nothing underneath the board which might cause a short circuit (do not place it on a metal surface!).

Before powering up the unit, wind all the trimpots and variable resistors to their minimum positions. This includes the six trimpots on the PCB and the two externally mounted adjustment potentiometers.

The best way to do the initial tests is with a variable DC supply fed into the BRIDGE+ and BRIDGE– leads with the appropriate polarity. You will need around 40V to ensure that REG1 is delivering the full 24V at its output.

If you don't have a 40V DC supply, you can feed 27-39V DC directly into REG1's input (with the positive lead clipped to the right-hand lead of the 220Ω 5W resistor). Or you can feed 24V into REG1's output, via the left-hand lead of the 68Ω 1W resistor. But in the latter case, any faults in REG1 itself may not show up.

It would be ideal if you can monitor the current drawn by the circuit; if your supply lacks an ammeter, you can monitor the voltage across the 220Ω 5W resistor, assuming that you are not bypassing this due to a lower test supply voltage.

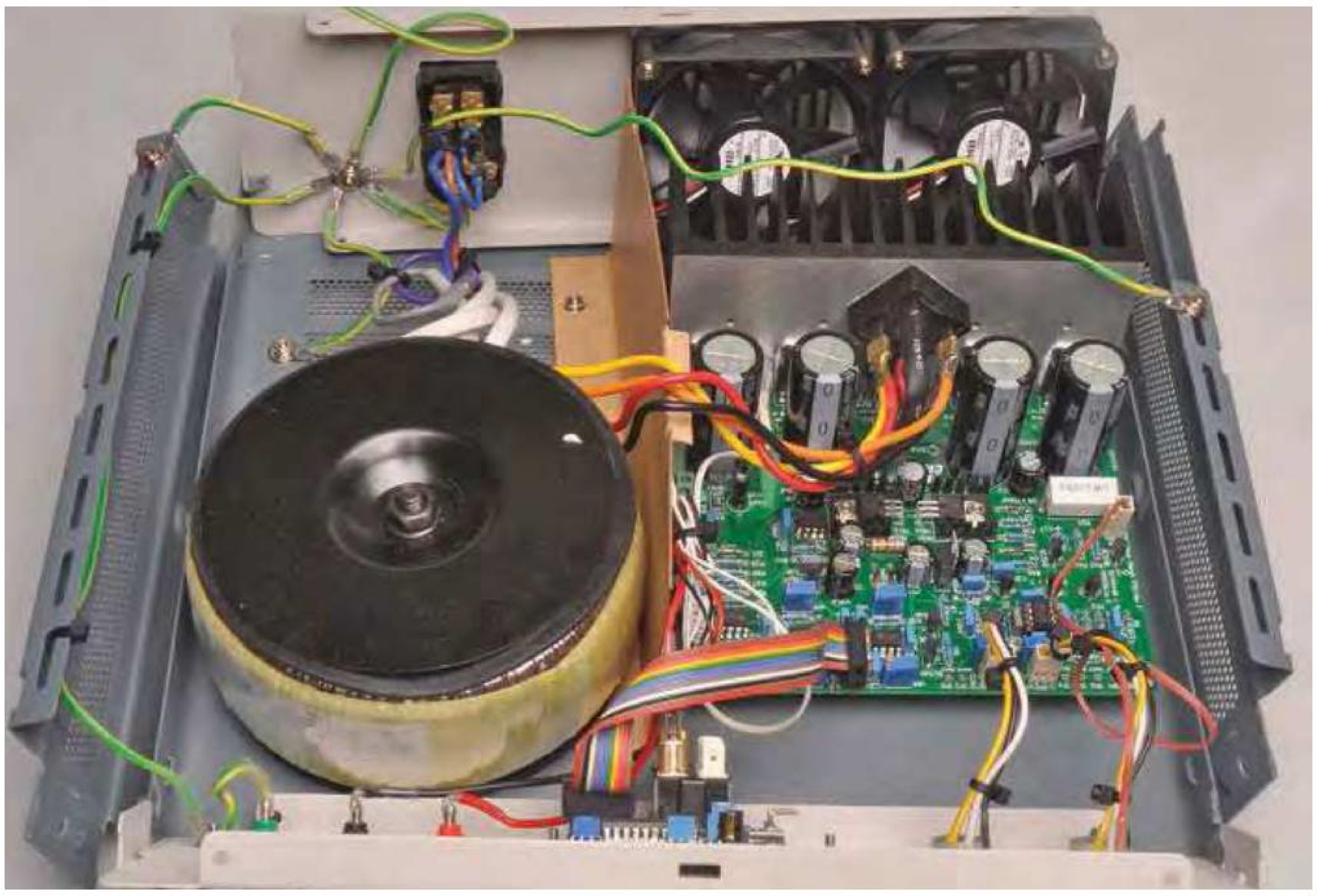
Power up the circuit and check the current draw. It should be around 60mA, which corresponds to 13.2V across the 220Ω resistor. If there is a severe fault, then you will see a much higher voltage across this resistor and it could get very hot. In that case, shut off power as soon as possible and check for faults. Any more than 20V across this resistor means that something is wrong.

Assuming the current draw is OK, you can now check the various voltage rails for correctness. Connect the negative multimeter probe to ground via TP0 and check the voltages with the positive probe. The 24V rail can be measured at the left end of the 68Ω resistor (assuming you aren't feeding power in there, as there would be little point in checking it then).

You should get a reading close to 24V, although it may be lower if your test supply does not have a high enough output. As long as it is above 18V, the remaining voltage rails should still be correct.

But you will not be able to complete the calibration until 24V is available from REG1, nor can you accurately calibrate the device if feeding power into the 24V rail.

The 12V rail can be measured at pin 4 or 8 of IC3. If the 12V rail is correct, then the negative rail generator should



We've 'opened out' this otherwise completed *Supply* to give you a better idea of what goes where and with what. Note the Presspahn insulation (fawn colour) which isolates the bitey bits from the rest of the circutiry – just in case,.

be working, and the tab of REG2 should have around –9V on it. The output of REG2 is connected to pin 4 on IC1, IC5 and IC6, and these should all be close to –5V.

Finally, the output of the +5V rail can be found at pin 1 of CON6 (marked '5V'). The outputs on CON6 marked A1-A4 correspond to the signals for the external panel meters. They should all read 0V if trimpots VR3 and VR4 are fully clockwise.

Pin A5 on CON6 should read around 3-4V if the thermistor is working correctly, but it may be a bit lower at high ambient temperatures.

If this is correct and you have built the *Five-way Panel Meter*, it can now be connected to CON6 to allow it to be calibrated (see the section on making the ribbon cable below, if you haven't already done so). All the readings, apart from the temperature, will be incorrect until calibration is complete.

If you are using individual panel meters, they can be connected now. Due to the limited current available from REG5, separate digital panel meters may need a separate 5V supply.

Initial calibration

Now check the voltages TP5 and TP6. TP5 should be at around 12V if VR1 has been wound to its minimum. Once you've verified that, adjust VR1 until TP5 measures 15.6V.

This sets up VR3 to provide 50V at the output when fully clockwise. This depends a little on the exact properties of trimpot VR3 itself, but this setting can be fine-tuned when construction is complete and you can measure the actual output voltage to full scale.

Similarly, adjust VR2 to get 6V at TP6, corresponding to approximately 8A at the output. This too can be fine-tuned later. If you wish to set a more conservative maximum current limit, you can adjust VR2 for a lower voltage at TP6.

At this stage, TP1 and TP3 should all be showing very close to 0V. If not, adjust VR3 and VR4 respectively so that this is the case. This ensures a minimum output voltage when the unit is fully powered up later.

TP2 and TP4 should also be near (or even below) 0V. This shows that the output voltage and current are both zero. You should not proceed unless this is the case, as there should be no output with REG3 absent. If you get positive readings here, check around IC1 and IC4 for circuit problems before proceeding with any high-power tests.

We will need to adjust VR4-VR7 later; this is not possible until the *Linear Supply* is fully assembled.

Other checks

If you have a frequency meter or oscilloscope, you can check the two oscillators. Their exact frequency is not critical, but significant variations can indicate other problems.

The oscillator for the negative rail generator is at pin 3 of IC3 and should measure around 60kHz. You should also check the duty cycle if possible; it should be close to 50% for maximum efficiency. If the duty cycle is wrong, and the negative rail is not reaching –5V, the values of the components around IC3 may be incorrect.

The frequency of the fan PWM circuit can be measured at pin 1 of IC2. This should be around 280Hz, with a 50% duty cycle. Pin 1 delivers a square wave, while pin 2 can be probed to check the 'triangular' waveform if you have a 'scope. With the thermistor near 25°C, the fan PWM output at pin 7 of IC2 should be off, so a voltmeter will read 0V.

If the thermistor is warmed up (such as by being held in a warm hand), the average voltage at pin 7 should rise to at least 3V, representing a 12V PWM signal with a duty cycle of around 25%. This indicates that the thermistor circuit is working as expected.

Mounting the power devices

Once you are happy with the results of the tests outlined above, the power components can be added to the board. Disconnect the power and allow the capacitors to discharge, which may take a minute or so.

The components in this area connect via thick tracks and may need more heat than the earlier components to solder.

Re-check now that the heatsink is free of swarf and metal dust, as these can puncture the transistor insulating pads and cause a short circuit. The face of the heatsink should be smooth. A light sanding with fine sandpaper will help to flatten any raised areas.

First, mount transistors Q3-Q7 and REG3 loosely to the heatsink. Use a 6mm M3 machine screw, insulating bush and insulating washer for REG3. The mounting for Q3 is the same as REG3 except that you'll need a longer, 10mm screw. Mount the four large transistors using 10mm-long M3 machine screws, with a thin smear of thermal paste over the side of the devices which touch the heatsink.

While Q3 is in a TO-126 package, a TO-220 insulating mounting kit will work fine with some careful trimming. Note that Q3 has its plastic face mounted against the heatsink, so the washer is more to ensure good contact than it is for insulation.

Check for continuity between the heatsink and leads of Q3 and REG3; there should be no continuity on any of the leads. You will need to probe the non-anodised face of the heatsink. If there is, remove that part, check the insulation and reattach. You must do this before soldering or fitting the PCB, as Q3's emitter is effectively connected to the heatsink via the collectors of Q4-Q7.

Now position the 3mm acrylic spacer next to the PCB, with the latter sitting on its 9mm tapped spacers. Line up the power device leads with the PCB pads and drop them into place, with the heatsink resting on the acrylic spacer.

Check the device mounting heights and adjust if necessary. Then solder

PARTS LIST – LINEAR 45V 8A BENCH POWER SUPPLY

1 double-sided PCB coded 18111181, 150 x 120mm available from the PE PCB Service
1 vented metal instrument case [Jaycar HB5556]
1 Five-way Panel Meter module (see article starting on page 36)
WITH 1 acrylic bezel [from PE PCB Service, coded 18111181-BZ]
OR 1 set of separate 5V panel meters and suitable mounting hardware
1 acrylic spacer for heatsink [Supplied ***with*** PCB 18111181 from the PE PCB Service]
1 40V 500VA toroidal transformer [element14 2817710]
1 35A 400V bridge rectifier (BR1) [Jaycar ZR1324, Altronics Z0091]
1 IEC mains input socket with fuse and switch [Jaycar PP4003, Altronics P8340A]
1 150 x 75 x 46mm diecast finned heatsink [Jaycar HH8555]
2 24V DC 80mm high-flow fans [Digi-key P122256]
2 80mm fan filter/guard [Jaycar YX2552]
2 TO-220 flag heatsinks, 6073B type (for REG1 and REG4) [Jaycar HH8502, Altronics H0630]
1 16V DC/230V AC 16A SPST or DPDT panel-mount toggle switch [Jaycar ST0581/ST0585]
1 208 x 225mm sheet of Presspahn or Elephantide [Jaycar HG9985]
2 TO-220 insulated mounting kits (for Q3 and REG3) [Jaycar HP1176]
1 2-way terminal block, 5mm pitch (CON1) [Jaycar HM3172, Altronics P2032B]
2 3-way polarised headers (CON2,CON3) [Jaycar HM3413, Altronics P5493]
2 3-way polarised plugs (for VR3 and VR4) [Jaycar HM3403, Altronics P5473 + P5470A)
4 2-way polarised headers (CON4,CON5,CON7,CON8) [Jaycar HM3412, Altronics P5492]
4 2-way polarised plugs (for LED1, thermistor and fans) [Jaycar HM3402, Altronics P5472 + P5470A]
1 6x2-pin header (CON6) [Jaycar HM3250, Altronics P5410]
2 12-pin IDC headers (to connect CON6 to Panel Meter) [Digi-Key 2057-FCS-12-SG-ND]
1 10kΩ stud-mount or lug-mount NTC thermistor [Digi-key 495-2138, Altronics R4112]
11 6.3mm spade crimp connectors (for BR1 and mains socket)
1 red chassis-mount banana socket/binding post
1 black chassis-mount banana socket/binding post
1 green chassis-mount banana socket/binding post
1 6A fast-blow M205 fuse (F1)
2 knobs (to suit VR3 and VR4)
4 instrument case feet and associated mounting hardware

Wire, cable, assembly material

1 1m length of 3-core 10A mains flex
1 1m length of 12-way ribbon cable (to connect CON6 to the Panel Meter module and to connect VR2, VR3, LED1 and the thermistor)
1 1m length of 10A-rated red wire (for BR1 and output terminals)
1 1m length of 10A-rated black wire (for BR1 and output terminals)
1 small tube of thermal paste
various lengths of 3mm and 6mm diameter heatshrink tubing
pack of small (2mm) cable ties
pack of self-adhesive wire clips

Fasteners

8 M3 x 32mm machine screws (for mounting fans)
1 M3 x 15-16mm machine screw and flat washer (for mounting BR1)
5 M3 x 12mm machine screws (for rear panel earth and mounting Panel Meter)
13 M3 x 9-10mm machine screws (for mounting fans and Q3-Q7)
18 M3 x 6mm machine screws (for panel earths, PCB mounting, REG1, REG3 and REG4)
4 M3 x 10mm nylon machine screws (for mounting heatsink)
8 M3 x 15mm tapped nylon spacers (for mounting fans)
4 M3 x 9mm tapped nylon spacers (for mounting PCB)
13 6.3mm spade crimp connectors (for BR1, the mains socket and output switch)
6 M3 crinkle or star washers (for panel earths)
16 M3 hex nuts (for panel earths, REG3, REG4 and mounting Panel Meter)
12 crimp eyelet lugs, 3mm inner diameter (for panel and output Earths)

Semiconductors

4 LM358 op amp ICs, DIP-8 (IC1, IC2, IC5, IC6)
1 555 timer IC, DIP-8 (IC3)
1 INA282 shunt monitor IC, SOIC-8 (IC4) [Digikey 296-27820-1]
1 7824 24V linear regulator, TO-220 (REG1)
1 7905 5V linear regulator, TO-220 (REG2)
1 LM317HV high-voltage adjustable regulator, TO-220 (REG3) [Digikey LM317HVT/NOPB]
1 7812 12V linear regulator, TO-220 (REG4)
1 78L05 5V linear regulator, TO-92 (REG5)
7 BC546 NPN transistors, TO-92 (Q1,Q2,Q8,Q9,Q11-Q13)
1 BD140 PNP transistor, TO-126 (Q3)
4 FJA4313OTU NPN power transistors, TO-3P (Q4-Q7) [Farnell 3368623]
1 IRF540N N-channel Mosfet, TO-220 (Q10)
1 5mm red LED with bezel (LED1) [Jaycar SL2610, Altronics Z0220]
1 6.8V 1W zener diode (1N4736 or equivalent; ZD1)
4 1N4148 signal diodes (D1-D4)
1 1N5404 400V 3A diode (D5)
1 SB380 80V 3A schottky diode (D6)

Capacitors

4 4700µF 63V electrolytic [Altronics R5228]
1 100µF 63V electrolytic
6 100µF 35V electrolytic
1 10µF 63V electrolytic
2 1µF 50V multi-layer ceramic
18 100nF MKT
1 1nF MKT

Resistors (all 1/2W 1% metal film unless otherwise stated)

4 1MΩ	3 100kΩ	1 27kΩ	1 22kΩ	16 10kΩ
1 9.1kΩ	1 2.2kΩ	5 1kΩ	1 220Ω§	1 100Ω
2 68Ω#	1 33Ω§	4 22Ω		

4 0.1Ω# [Digi-Key 0.1GCCT-ND, Mouser 603-KNP1WSJR-52-0R1]
1 0.015Ω 2W or 3W, SMD 6432/2512 size [Digikey YAG2165CT, Mouser 603-PE252FKE7W0R015L]
6 10kΩ vertical multi-turn trimpots (VR1,VR2,VR5-VR8)
2 10kΩ linear 24mm potentiometers (VR3,VR4)
Resistor notes: # 1W 5% § 5W 10%

one lead at each end of each device. You can then carefully flip the whole assembly over and solder all the pins thoroughly, with the PCB resting on something to prevent it sagging under its own weight. When finished, trim the leads short.

Tighten up all the screws holding the devices to the heatsink and check that they are firmly attached, as once the large electrolytic capacitors are fitted, access will be limited. Now would be a good opportunity to re-check that REG3 and Q3 are still insulated from the heatsink.

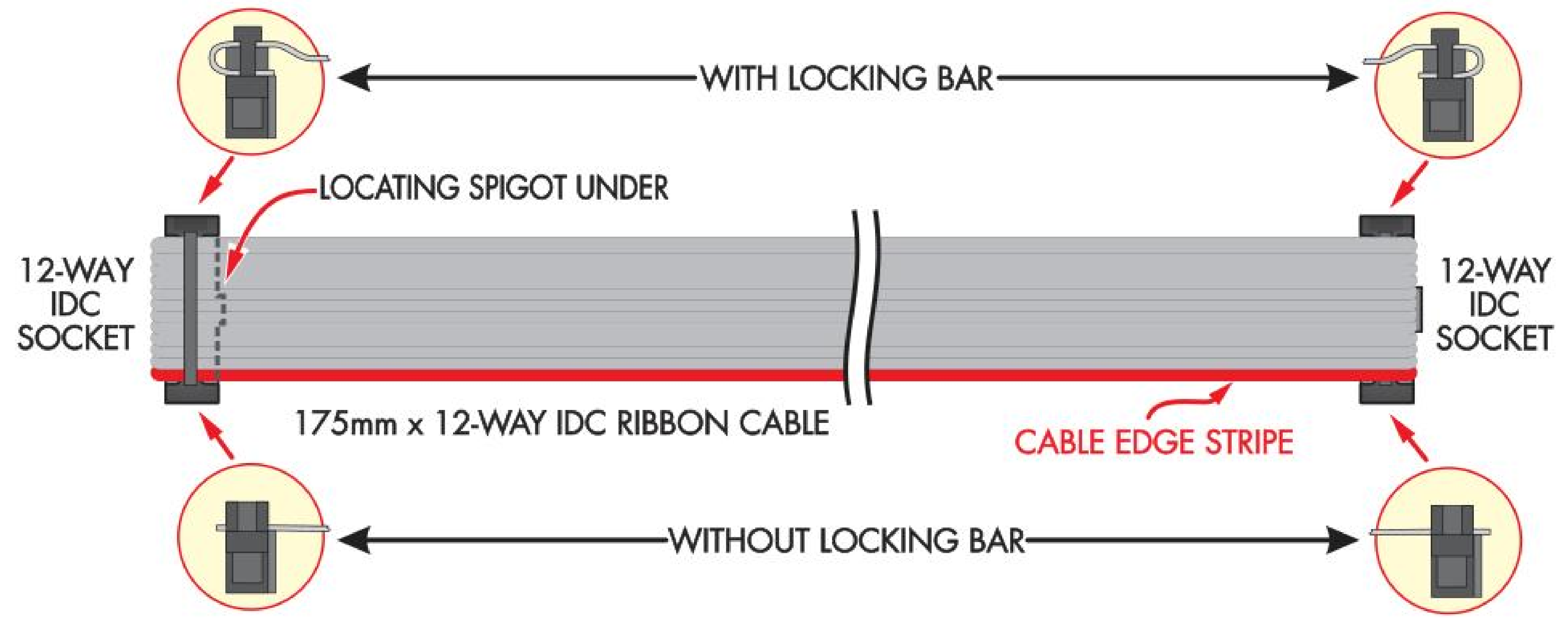


Fig.7: this shows how to make the ribbon cable which connects the *Five-way Panel Meter* to the *Linear Bench Supply* main PCB. Whether your cable looks like the pictures in the upper or lower circles depends on your type of IDC connector.

Next, smear the face of BR1 with thermal paste and attach it to the heatsink using a 16mm-long M3 machine screw and flat washer. Install it with the positive terminal at the bottom. This means that the wires do not need to cross over to reach the PCB terminals. The bridge has a bevel to identify the positive terminal, and will typically also be printed with a '+' symbol on the side.

Connect the BRIDGE+ and BRIDGE– terminals to the bridge rectifier by pushing the spade connectors onto its tabs.

The final components to fit are the four 4700µF 63V capacitors mounted directly in front of the output transistors. Their negative stripes must face towards the front edge of the PCB. Solder them in place and trim the leads to complete the component assembly.

Now is a good time to attach the thermistor to the heatsink. If using the stud-mount type, thread it into its hole on the heatsink. If using the lug type, attach it with a machine screw and shakeproof washer. Mount it on the flat side of the heatsink so that it is not directly cooled by airflow from the fans.

Check the thermistor leads for continuity against the heatsink; there should be none. If there is, check the mounting and re-insulate as necessary.

IDC ribbon cable assembly

Now is a good time to make up the IDC cable that will connect the *Five-way Panel Meter* to the control board (assuming you're using that meter and not some other arrangement). Cut a 175mm length of 12-way ribbon cable and attach the IDC sockets at each end with the same orientation. So with the cable stretched out flat, the two polarising tabs on the IDC connectors should face the same way.

If you can't get 12-way ribbon cable, take some wider ribbon cable, cut between the 12th and 13th wires and then gently pull the two sections apart. They should separate cleanly.

See Fig.7 for details on how to make this cable. Usually, IDC connectors are supplied as three pieces: the main part of the connector, with holes to mate with the pin header on the bottom and blades to slice through the cable insulation on the top; a plastic clamp, which is pressed down on the top of the cable to force it into the blades, and a locking bar which provides strain relief and holds it all together.

The way the cable is fed through these three-piece IDC connectors is shown at the top of Fig.7. But the 12-way IDC sockets we purchased only consisted of two pieces, with the clamp and locking bar integrated and no provision for cable strain relief. This arrangement is shown in the lower two circles. Make your cables to match one or the other, depending on the style of IDC sockets that you have sourced.

It's essential to use sufficient clamping force to ensure that the blades properly pierce the cable insulation and make contact with the copper strands within, without pressing so hard that you break the plastic.

You can do this in a vice; however, a proper IDC crimping tool generally makes the job easier (for example, Altronics Cat T1540).

More testing

Now that you've finished assembling the control board, assuming you have a suitably safe source of AC or DC power, you can do some more testing.

Plug in the *Five-way Panel Meter*, VR3, VR4, thermistor and LED, and then apply power to the two unconnected terminals of BR1. You can use 24-40V AC or 30-58V DC.

If you can limit the current to a few hundred milliamps, that's a good idea, but note that this will mean that it takes some time for the main capacitor bank to charge, and it will draw the maximum current as it does so.

Once the *Linear Bench Supply* is powered up, check that the *Panel Meter* powers up too. You may need to tweak the brightness and contrast if these have not been set.

The voltages and currents should all read zero as VR5, VR6, VR7 and VR8 should have all been set to their minimum and have not been calibrated. The temperature shown on the *Panel Meter* should be around ambient if the thermistor is wired up correctly.

Assuming that it checks out OK, power it off; it's time to start preparing the case.

We'll have the full details on the final assembly and testing in *Part 3*, next month.

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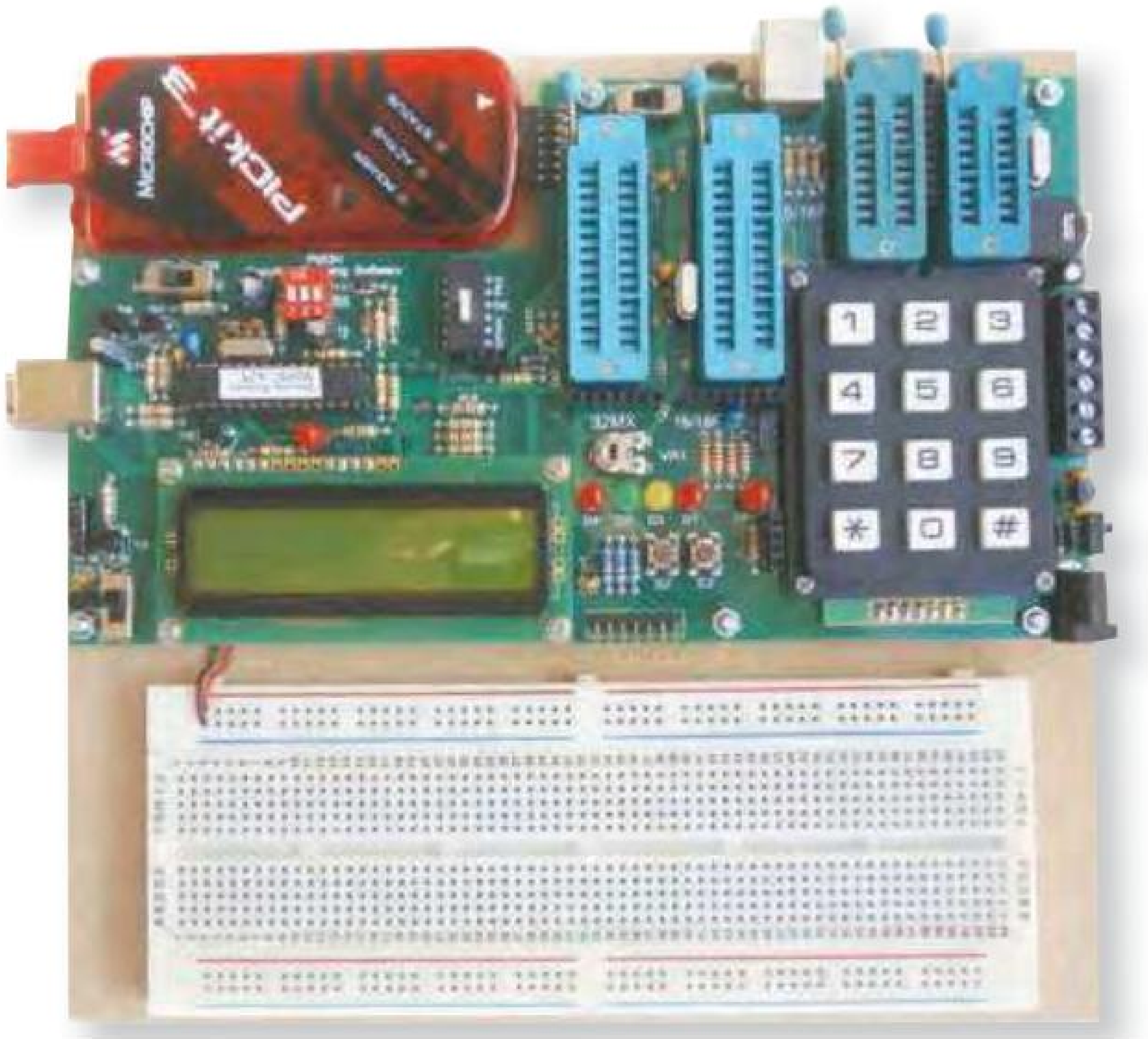
We'll cover the final assembly of the supply in the third and final part of this project next month.

P955H PIC Training Circuit

by Peter Brunning



When you are first learning about PICs, whether you are a complete beginner or an experienced programmer, you need an uncomplicated system which allows you to learn without getting bogged down in system procedure. That is why we created the P955H PIC training circuit and our own PIC assembler. In the first book we learn about PIC programming using the Brunning Software PIC assembler BSPWA, but in chapter 3M there is an introduction to the Microchip assembler MPASM X. All our assembler text will run in both systems, so from there on, if you wish you can use MPASM X. Likewise, we start by using the on-board PIC programmer to write the code into the PIC, but if you prefer, plug in a PICkit 3 or 4 and use that. The P955H training circuit has the flexibility to be what you need as your learning process advances.

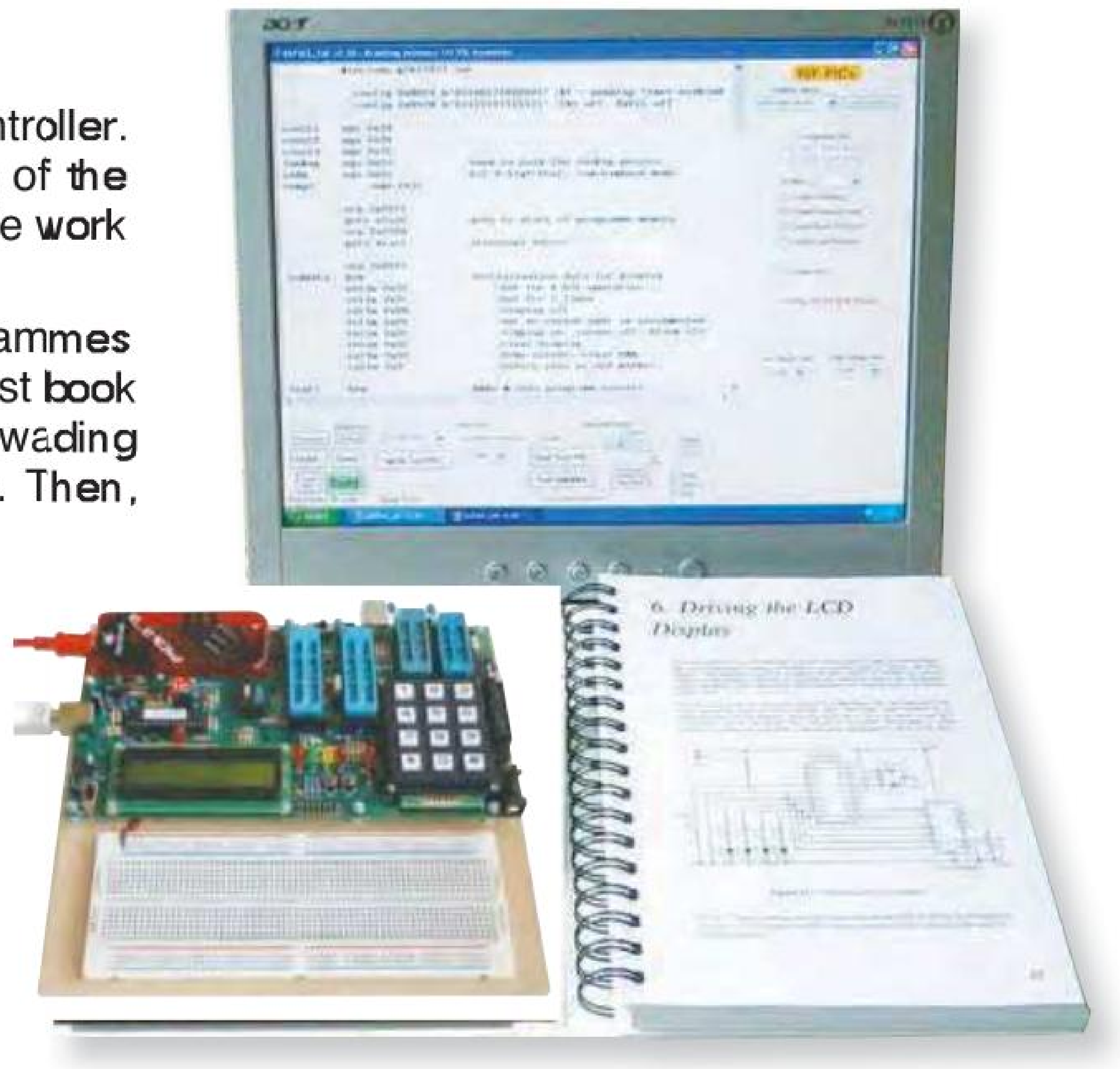
The P955H training circuit has been designed to work with both 32-bit and 8-bit PICs. The idea is to start learning about PICs using assembler with 8-bit PICs. Then learn C with 8-bit PICs, study serial communications using 8-bit PICs, and finally study C programming using 32-bit PICs. It is a simple approach to a subject that has no limit to its ultimate complexity.

The Brunning Software P955H PIC Training Course

We start by learning to use a relatively simple 8-bit PIC microcontroller. We make our connections directly to the input and output pins of the chip and have full control over the internal facilities of the chip. We work at the grassroots level.

The first book teaches absolute beginners to write PIC programmes using assembler, which is the natural language of the PIC. The first book starts by assuming you know nothing about PICs, but instead of wading into the theory we jump straight in with four easy experiments. Then, having gained some experience, we study the basic principles of PIC programming, learn about the 8-bit timer, how to drive the alphanumeric liquid crystal display, create a real-time clock, and experiment with the watchdog timer, sleep mode, beeps and music. Then there are two projects to work through. In the space of 24 experiments, two project and 56 exercises we work through from absolute beginner to experienced engineer level using the latest 8-bit PICs (16F and 18F).

The second book introduces the C programming language for 8-bit PICs in very simple terms. The third book, *Experimenting with Serial Communications*, teaches Visual C# programming for the PC so that we can create PC programmes to control PIC circuits.



In the fourth book, we learn to programme 32-bit MX PICs using fundamental C instructions. Flash the LEDs, study the 16-bit and 32-bit timers, write text to the LCD, and enter numbers using the keypad. This is all quite straightforward as most of the code is the same as already used with the 8-bit PICs. Then life gets more complex as we delve into serial communications with the final task being to create an audio oscilloscope with advanced triggering and adjustable scan rate.

The complete P955H training course is £259, which includes the P955H training circuit, four books (240 × 170mm, 1200 pages total), six PIC microcontrollers, PIC assembler and programme text on CD, two USB-to-PC leads, a pack of components, and carriage to a UK address. (To programme 32-bit PICs you will need to plug in a PICkit 3 or 4. You can buy PICkit 4 from Microchip for £44).

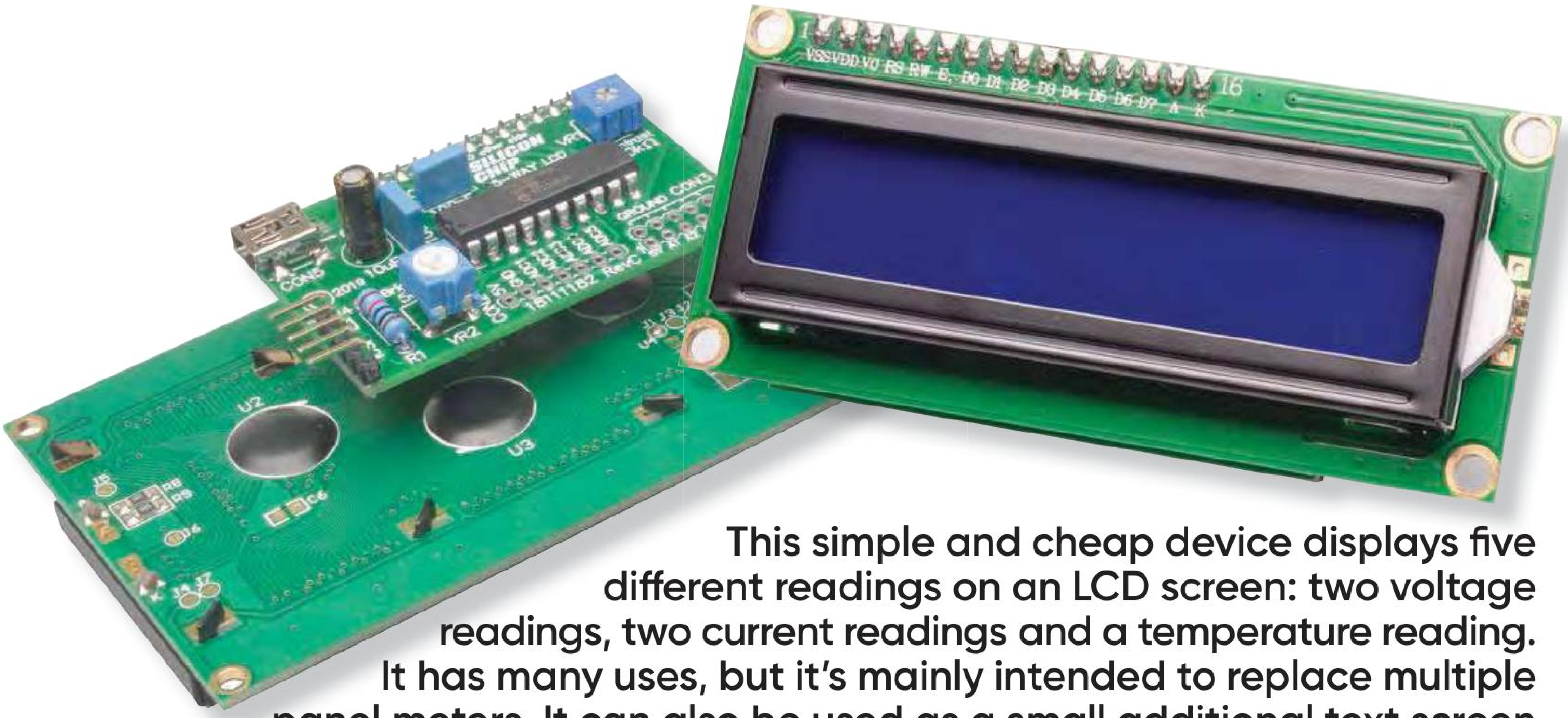
Prices start from £175 for the P955H training circuit with Books 1 and 2 (240 × 170mm, 624 pages total), two PIC microcontrollers, PIC assembler and programme text on CD, USB-to-PC lead, and carriage to UK address. (PICkit 3 or 4 not needed for this option.) You can buy Books 3 and 4, USB PIC, 32-bit PIC and the components kit as required later. See the Brunning website for details: **www.brunningsoftware.co.uk**

Mail order address:

Brunning Software

138 The Street, Little Clacton, Clacton-on-sea,
Essex, CO16 9LS. Tel 01255 862308

FIVE-WAY LCD PANEL METER / USB DISPLAY



This simple and cheap device displays five different readings on an LCD screen: two voltage readings, two current readings and a temperature reading. It has many uses, but it's mainly intended to replace multiple panel meters. It can also be used as a small additional text screen for a PC, Raspberry Pi or any other computer with USB.

by Tim Blythman

We came up with this idea for a *Panel Meter/USB Display* while working on the *Linear Bench Supply* that started last month (*Part 2* starts on page 28 of this issue).

We needed a way to show several different voltage and current readings, along with heatsink temperature, and it just didn't make sense to use several panel meters for that job.

It's difficult enough to cut a single neat rectangle in the front panel of the instrument case to fit one screen, let alone three or even five. And there would be a lot of extra wiring if we used separate panel meters, plus increased current draw and it could end up being pretty expensive.

This single low-cost device, using a micro, an LCD screen and not much else, makes the whole thing so much easier.

There are two ways to use this board. In the *Linear Bench Supply* we're feeding in five analogue voltages with a common ground. These voltages are a fraction of the actual measured voltages (ie, the outputs of voltage dividers). The onboard micro samples these voltages and converts the values back to the original scales, then displays them on the screen.

In the case of the fifth input, which is used for temperature sensing via an NTC thermistor, it also performs the required calculations to deal with the non-linear behaviour of the NTC.

In the other mode, the micro detects when it is plugged into a USB interface and then behaves differently. You send it text over a virtual serial link, which is shown on the display. So you can easily show whatever you want on the 16×2 or larger 20×4 character backlit LCD screen.

More details

Our *45V 8A Linear Bench Supply*, mentioned above, has five main parameters to monitor. Those are the wanted voltage and current, the actual output voltage and current (which may be lower than the desired values in some cases), plus the heatsink temperature.

It will automatically switch on fans if the heatsink gets hot, and throttle back its output in the worst case if that doesn't help. But it's still handy to have a way to tell how close to the wind you're sailing!

We settled on using a PIC16F1459 microcontroller to monitor and display these voltages. It's a low-cost micro with some nice features. It's similar to the PIC16F1455, but it has more I/O pins, which makes it easier for us to interface with an LCD panel.

Both the 16F1455 and 16F1459 have USB interfaces, making it easy for us to implement the USB mode as a 'bonus' feature.

In this bonus mode, it is effectively a character LCD that can be controlled from your computer. If you

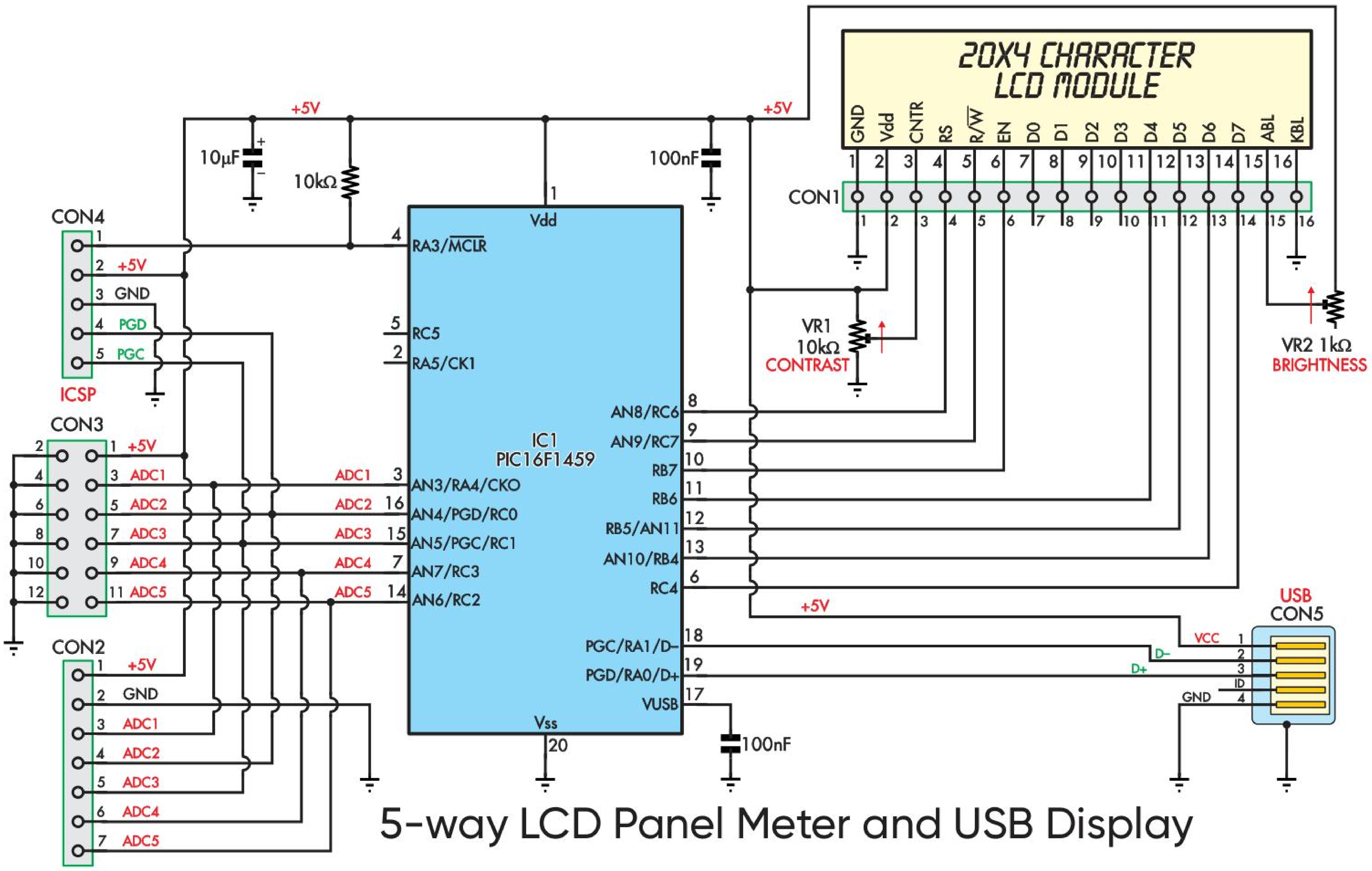


Fig.1: the circuit is quite simple. Microcontroller IC1 uses its internal analogue-to-digital converter and 4.096V reference to measure the voltages at the ADC1-ADC5 inputs. It then scales the readings from ADC1-ADC4 and converts the reading from ADC5 to a temperature before updating the LCD connected via CON1. In *USB Display* mode, it instead receives text from a PC via CON5 and updates the display.

want some extra information displayed 24/7 without needing to have a full-size monitor switched on and drawing power the whole time, it's an ideal solution.

It's even small enough to be mounted in a desktop computer's drive bay.

You could use it to display things like CPU load, memory usage, disk space usage, network activity, instant messages, unread e-mails... the list is virtually endless.

You just need to figure out how to get that information and send it to a serial port, and the *Display* does the rest.

Circuit description

The circuit of the *Display* is shown in Fig.1. The aforementioned PIC16F1459 microcontroller is shown as IC1.

Its 5V power supply comes from either pin headers CON2/CON3, when used in the panel meter role, or CON5, the USB socket. The data pins from the USB socket are connected directly to pins 18 and 19, the dedicated USB data pins of IC1.

In the panel meter role, the five voltages are fed into either SIL header CON2 or DIL header CON3, whichever is more convenient. CON3 has the advantage that an IDC header on a 12-way ribbon cable can plug straight in, and each signal wire will have a ground wire on either side, minimising noise pickup

The five signal lines go straight to analogue inputs AN3, AN4, AN5, AN7 and AN6 of IC1 (pins 3, 16, 15, 7 and 14). IC1's internal 10-bit analogue-to-digital converter is used to read these 0-4.096V signals and convert them to digital values, with a resolution of 4mV ($4.096V \div 2^{10}$)

The 4.096V reference is within IC1, and we're using this rather than the 5V rail so that variations in the 5V supply do not affect these readings. That means we don't need to be concerned about how well regulated the 5V rail is.

These are scaled in software to the values shown in the spec panel, which are designed to suit our power supply, but these values will be useful for a range of low-voltage DC monitoring tasks.

You simply need to arrange for shunts to monitor currents, and dividers with approximately the right ratios (around 15:1 for voltages) plus trimpots for calibration, to feed the right voltage ranges to the panel.

An HD44780-based character LCD screen is connected via 16-way header CON1. It is driven in four-bit mode, with the RB6, RB5, RB4 and RC4 digital outputs of IC1 (pins 11, 12, 13 and 6) driving LCD data pins DB4-DB7.

We only need four data pins as these LCDs can operate in a four-bit mode, with the D0-D3 I/Os left floating or tied to ground.

Digital outputs RC6, RC7 and RB7 (pins 8-10) of IC1 drive the RS, R/W and EN pins of the LCD, controlling when the data is clocked and whether the LCD should treat it as an internal command or send it to the display.

Trimpot VR1 adjusts the LCD contrast voltage, while VR2 is wired as a variable resistor in series with the backlight LED, allowing its brightness to be set.

The power supply is simple. There is a 10µF bulk bypass capacitor for the 5V rail, which is the maximum value allowed to meet the USB inrush current specification. IC1 has its own high-frequency 100nF local bypass capacitor.

A 10kΩ resistor pulls up the micro's MCLR pin to 5V to prevent spurious resets, while a 100nF capacitor between pin 17 (VUSB) and ground stabilises its internal USB 3.3V regulator.

The ICSP header, CON4, is provided to allow the PIC to be programmed without having to be removed.

Using it as a panel meter

On power-up, if no USB connection is detected, it will initialise the LCD and show a splash screen. The analogue pins are set as inputs, and the analogue-to-digital converter (ADC) voltage reference value is set to the internal 4.096V fixed reference.

After a second, it begins sampling the analogue pins around five times per second. The update interval gives a quick update time, but not so fast that the numbers would blur into each other while changing.

The current and voltage values are converted using fixed internal scaling factors, with the idea being that they have been fine-tuned using external trimpots. The reading from the thermistor is used to find the temperature in a look-up table stored in Flash.

The header on CON3 matches the pinout of CON6 on the *Linear Bench Supply* to allow a direct connection. If the input assignments or scaling ratios don't suit your particular application, you can download the source code from our website and change it to better suit your needs.

It is written in the C language. Microchip's MPLAB X IDE software is a free download, and there is a free version of the XC8 compiler (plus a trial mode for the full compiler).

Once you have installed that software, you can open up the project, make some changes to the code and then 'Build' the project to produce a new .hex file for IC1.

We used MPLAB X IDE Version 5.05 and XC8 Version 2.00 and our compiled HEX file was very close to the 8kB limit. We suggest using the same version to avoid going over this limit.

Using it as a USB display

When connected as a USB display, neither CON2 or CON3 are needed as the analogue pins are not sampled. On power-up, IC1 enumerates on the connected USB port as a USB-serial device and appears as a serial port to the host.

For example, this would be a COM port on Windows or a TTY device on Linux. The LCD is initialised and blanked, and a default set of character graphics are loaded into code points 0-7.

When data is received from the host, (for example, if you were typing into a serial terminal program), it is processed by IC1 and used to update the display. ASCII characters are passed straight on to the LCD, while control characters such as CR (carriage return, ASCII code 13) and LF (line feed, ASCII code 10) move the printing location as expected.

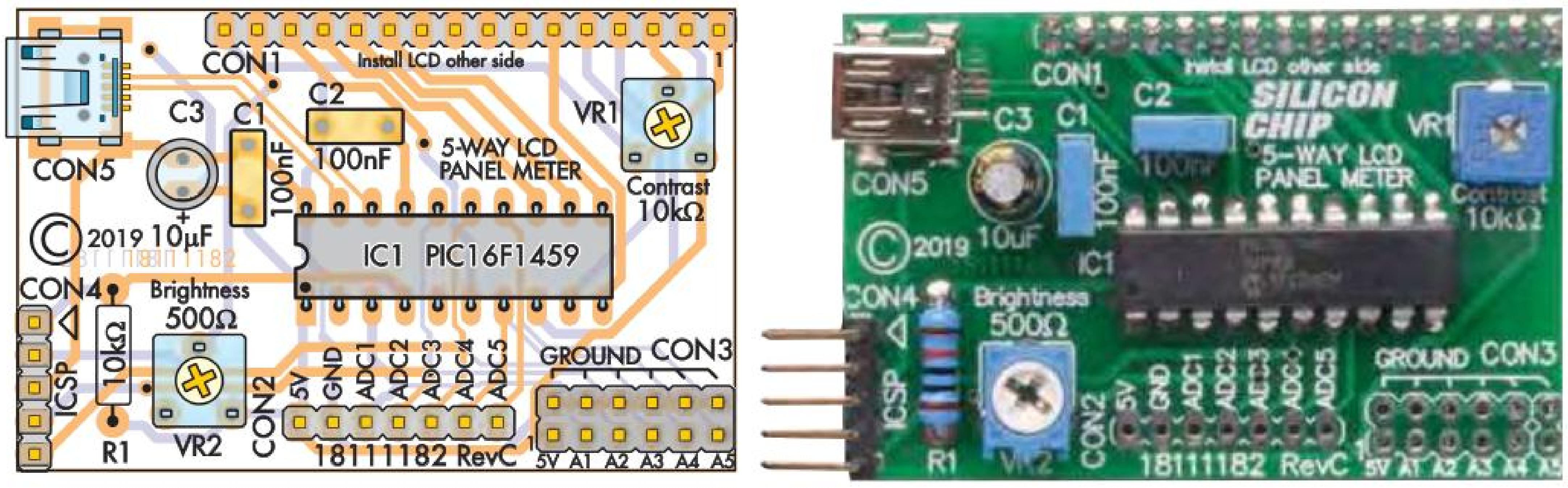


Fig.2: use this PCB overlay diagram and the same-size photo at right as a guide to help build the *Panel Meter/USB Display board*. The only polarised components are IC1 and the electrolytic capacitor. You can use a socket for IC1 if you want to. CON5 is not required for the *Panel Meter* version, while CON2-CON3 are not required for the *USB Display* version; and CON4 is only needed if you plan to program IC1 in-circuit.

TAB moves to the next screen position which is a multiple of five characters, while **FF** (form feed, ASCII code 12) moves the cursor to the home position.

Backspace (ASCII code 8) moves back one position, but does not erase anything. A true erasing backspace can be simulated by a backspace, space, backspace sequence consisting of ASCII codes 8, 32 and 8.

Finally, **Escape** (ASCII code 27) clears the screen, but does not move where the display will print next. Thus a sequence of **ESC** and **FF** returns the display to the same state as it is when it first starts up.

The entire display is held in a RAM buffer and sent to the LCD one character at a time, to ensure that the USB peripheral is not left waiting too long for the display to update. This could otherwise happen if the display needs to be cleared and many characters need to change at the same time.

While this might sound slow, the display can still fully update around 10 times per second.

The RAM buffer consists of four rows of 20 characters, as this is the largest display size that the HD44780 controller can manage. Text wraps around at the end of a line and back to the top at the end of the last line. If a smaller display is fitted, it will appear the same as the top, leftmost corner as a larger display would appear.

Thus the display operates fairly intuitively and can be easily controlled by any software that can write to a serial port. No data is sent by the USB display back to the host, so the receiving program should not expect to deal with this.

Construction

The *Panel Meter/USB Display* is built on a double-sided PCB coded 18111182, which measures 56 × 36mm and is available from the *PE PCB Service*.

The PCB overlay diagram (Fig.2) shows where to fit the components. As noted above, some parts can be left out for some applications. We will describe the installation of all parts, which will allow the unit to be used as either a panel meter or USB display.

The only surface-mount part is the USB socket, and it should be fitted first. A soldering iron with a fine tip will make this easier. We recommend that you have flux and solder wick (braid) on hand for this step. A pair of tweezers can be helpful too.

Apply flux to the four pads on the PCB for the USB data and power signals. These are the four parallel pads to the right of the socket. Place the socket on the PCB; it should lock into place due to the two small posts on its underside.

Carefully apply solder to the pads and pins, ensuring all four are well attached. If there is any bridging, apply more flux and use the solder braid to remove it. Then apply flux paste to the four larger mechanical pads and solder them to their respective pads too. They are larger and will need more heat.

Next, mount the single resistor, followed by the two non-polarised 100nF capacitors. Follow with the electrolytic

Features and specifications

* *Shows two voltages, two currents and one temperature reading on a 16×2 LCD*
* *In alternative USB mode, ASCII text from a virtual serial port is written directly to a 20×4 LCD*
* *Panel meter input range: 5 × 0-4.096V*
* *Panel meter scaling: 2 × 0-4.096V -> 0-60V, 2 x 0-4.096V -> 0-9A, 1 x 0-3V -> 0-100°C*
* *Panel meter resolution: 58.6mV for voltages, 8.79mA for currents*
* *Panel meter update rate: 5Hz*

capacitor, which is polarised. It must be installed with its longer positive lead to the pad marked '+' on the PCB.

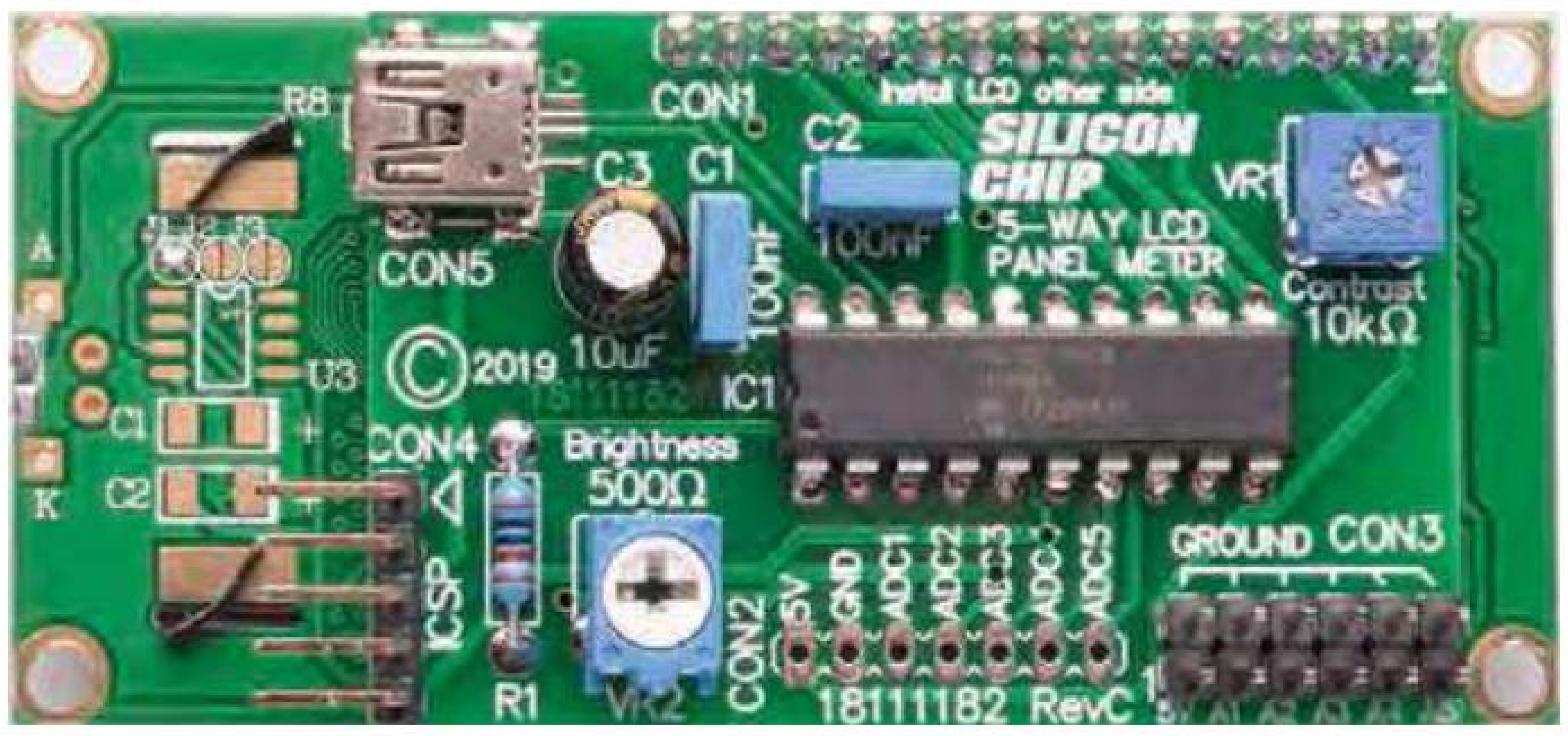
Now fit trimpots VR1 (10kΩ, 'Contrast') and VR2 (500Ω, 'Brightness'). Push them down, and they should both snap into place, after which you can solder their pins. If you are using a socket for IC1, install this next, ensuring the notch goes to the end closest to the USB socket.

If you have fitted the socket, gently straighten IC1's pins so that it will slot into the socket, then plug it in. If soldering IC1 directly to the PCB, start with two diagonally opposite pins. Once you are happy that the IC is flat against the PCB and oriented correctly, solder the remaining pins.

You can now mount CON2 and CON3. For CON2, you could use either a header or socket, while CON3 is designed to be fitted with a double-row male header to allow an IDC socket (plug) and cable to be attached.

If fitting CON4, do so next. You can use a straight or right-angle header; we prefer the right-angled variety in this role as it allows the programmer to sit flat when connected. CON1 should be fitted last, as it also needs to be attached to the LCD. You may choose to solder it directly, or use a female header socket on the panel meter PCB to allow the LCD to be removed.

We recommend attaching the male header to the LCD first by soldering one pin and ensuring it is straight and flush with the LCD's PCB. Then solder the remaining pins.



The PCB sits neatly within the footprint of the 16×2 LCD panel, leaving the mounting holes clear. Using a female header on the PCB means it can be removed if necessary.

Before soldering the LCD to the main board, check that its pinout matches that shown in our design.

Most LCDs with a SIL header should have a pinout that matches ours, but checking this now can save much troubleshooting later if you somehow have one that's different (see Fig.1). If there is a pin mismatch, you can solder only the matching pins and then use insulated wire to make the remaining connections.

You may like to slip a piece of card between the two to maintain spacing while soldering. Check that your boards are oriented the same way as in our photos. If you are using a header socket to attach the LCD, plug in the male header before soldering. This will allow you to check that all the clearances are correct.

Programming IC1

This step is not necessary if you purchased a pre-programmed PIC.

You can use a PICkit 3, PICkit 4 or SNAP programmer to flash IC1 on the board via the ICSP header (CON4).

(Note that the SNAP programmer cannot provide power to the micro and only supports low-voltage programming. So if you are using the SNAP programmer, you need to provide power via another source, such as the USB socket, and ensure that the low-voltage programming option is selected in the software.)

Regardless, you will need Microchip's IPE (integrated programming environment), which can be downloaded as part of the MPLAB X IDE from: **www.microchip.com/mplab/mplab-x-ide**

In the IPE, select '16F1459' in the device drop-down menu and your programmer from the tool menu, if it isn't already selected.

Connect the programmer to CON4 on the PCB, lining up the two pin 1 indicator triangles.

Then click the 'Connect' button in the IPE and ensure that the connection is successful, according to the display in the lower output window.

Then you just need to open the HEX file and click the 'Program' button to upload it to the chip.

Connecting the panel meter

Details for connecting the *Panel Meter* to the *Linear Bench Supply* are included in that article.

If you wish to use it for another purpose, then connect the 5V and ground pins to a 5V supply and the five analogue pins to sources of appropriate analogue voltages.

The ADC1 and ADC2 inputs are scaled to display 0-60V for an input of 0-4.096V, while ADC3 and ADC4 are scaled to 0-9A for 0-4.096V.

You will need to use a 10kΩ NTC thermistor wired as a divider with a 6.2kΩ resistor across a 5V supply to feed the ADC5 input if you are to get meaningful readings.

Fig.3 shows our suggested circuitry for interfacing with the *Panel Meter*. If you're using a different shunt value, you will need to use a different shunt monitor IC, or provide some gain at its output, to get at least 4.096V for a current of 9A, giving the correct scaling. That's regardless of whether your circuit will reach 9A.

Once the *Panel Meter* is connected to such a circuit, it simply converts the analogue inputs and displays the measured values, and no other action is required. You may need to adjust the contrast and brightness, as described below.

Parts List – Five-way LCD Panel Meter/Display

1 double-sided PCB coded 18111182, 56mm x 36mm, available from the PE PCB Service
1 16x2 character LCD with backlight (for Panel Meter, eg, Jaycar QP5521) ***OR***
1 20x4 character LCD with backlight (for USB Display, eg, Jaycar QP5522)
1 16-pin male header (CON1)
1 16-pin header socket (optional, to allow LCD to be unplugged)
1 7-pin header or header socket (CON2; optional)
1 2x6-way pin header (CON3; not needed for USB Display)
1 6-way right-angle header (CON4; optional)
1 SMD mini-USB socket (CON5; not needed for Panel Meter)

Semiconductors
1 PIC16F1459-I/P microcontroller programmed with 1811118A.HEX

Capacitors
1 10µF 10V electrolytic
2 100nF MKT or multi-layer ceramic

Resistors
1 10kΩ 1/4W 5%
1 10kΩ mini horizontal trimpot (VR1)
1 500Ω mini horizontal trimpot (VR2)

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- USB configuration
- Isolated
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- 30 V / 2.5 A

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- Lowest power consumption
- Smallest and lightest
- 7 in 1: Oscilloscope, FFT, X/Y, Recorder, Logic Analyzer, Protocol decoder, Signal generator

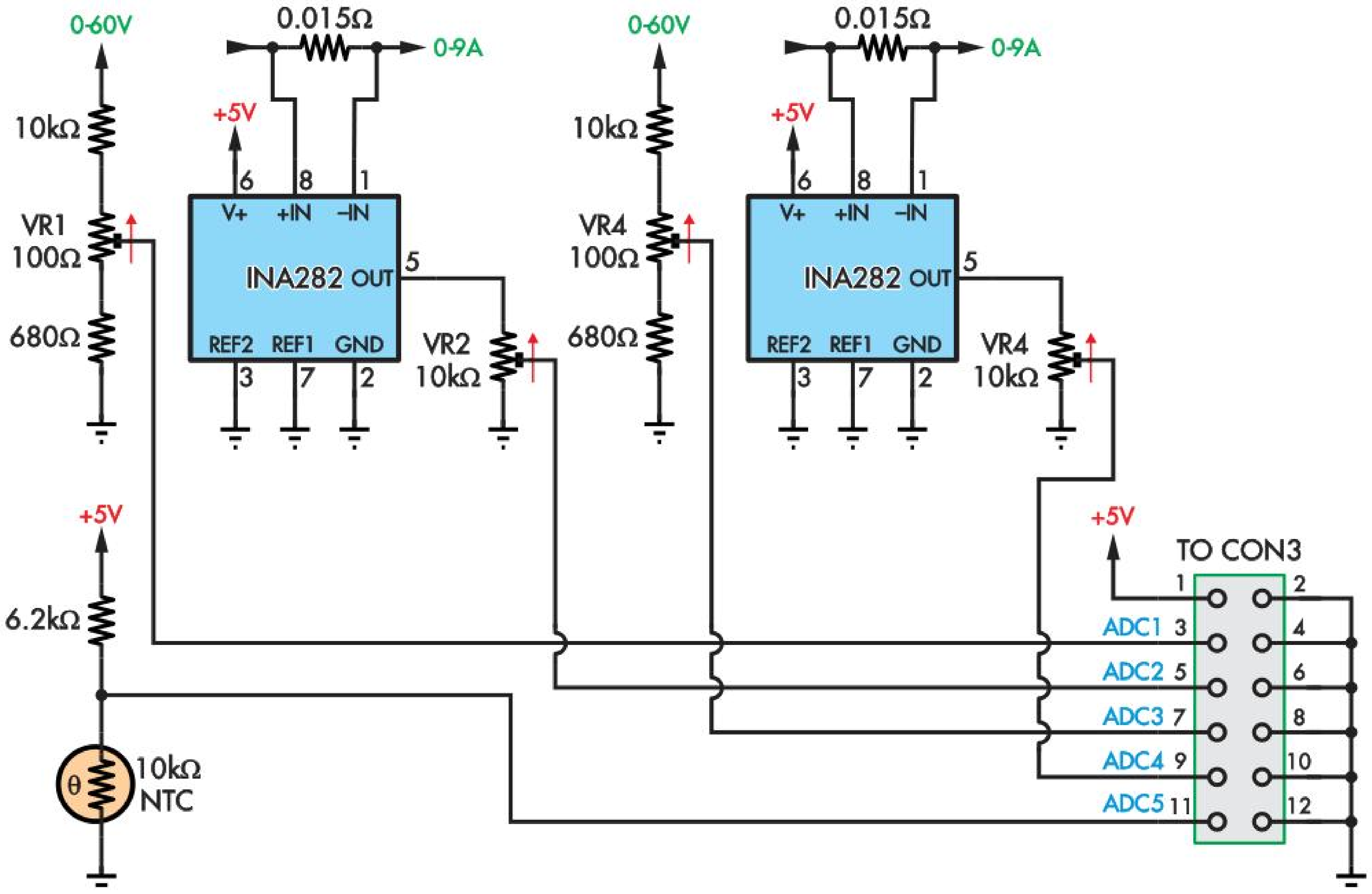

Fig.3: interfacing the *Panel Meter* to your own circuitry. If you're using low-side shunts to monitor current, you could use op amps to amplify the voltage across them to a suitable level for feeding to the *Panel Meter*. You could also use lower-value shunts in combination with a higher-gain shunt monitor for less heating and power loss.

Using it as a USB display

To use the unit as a USB display, simply plug it into a computer with a mini type-B to type-A USB cable.

You may need to install a driver, in which case the same driver is used as for the Microbridge. This is because the Microbridge uses the similar 16F1455 microcontroller in a similar role.

This should not be necessary for Windows 10, Linux or Mac users. If needed, the driver can be downloaded from: **www.microchip.com/wwwproducts/en/MCP2200**

Once the driver is installed and the USB device enumerated on your system, it can be tested by using a serial terminal program such as PuTTY, TeraTerm or even the Arduino Serial Monitor.

Open a connection to the appropriate port and type characters into the terminal. You should see them appear on the LCD. If not, you may need to adjust your LCD's contrast and brightness.

The baud rate is not critical because the virtual serial port enumerated by IC1 does not use this information (as it might if it were connected to a downstream hardware UART).

Contrast and brightness

No matter what the brightness setting, the backlight LED should be on. If you cannot see anything on the display, the contrast probably needs to be adjusted.

Turn VR1 until characters can be seen clearly against the background. Once the characters are clear, you can then tweak the brightness.

On the unit we built, we had good contrast with around 1.8V on pin 3 of CON1, although this may vary depending on the specific display module used in your LCD.

If you have built the USB display and cannot see any characters, make sure you have sent some data to the terminal. If it is still not working, there may be a problem with the construction, probably to do with the LCD if the USB side is enumerating correctly.

Conclusion

While this was originally designed to replace multiple panel meters for our *Linear Bench Supply* project, we've also turned it into a handy accessory for a computer.

It just goes to show how versatile the PIC16F1459 is. We're sure you'll find plenty of other uses for this flexible, inexpensive and easy-to-build display!

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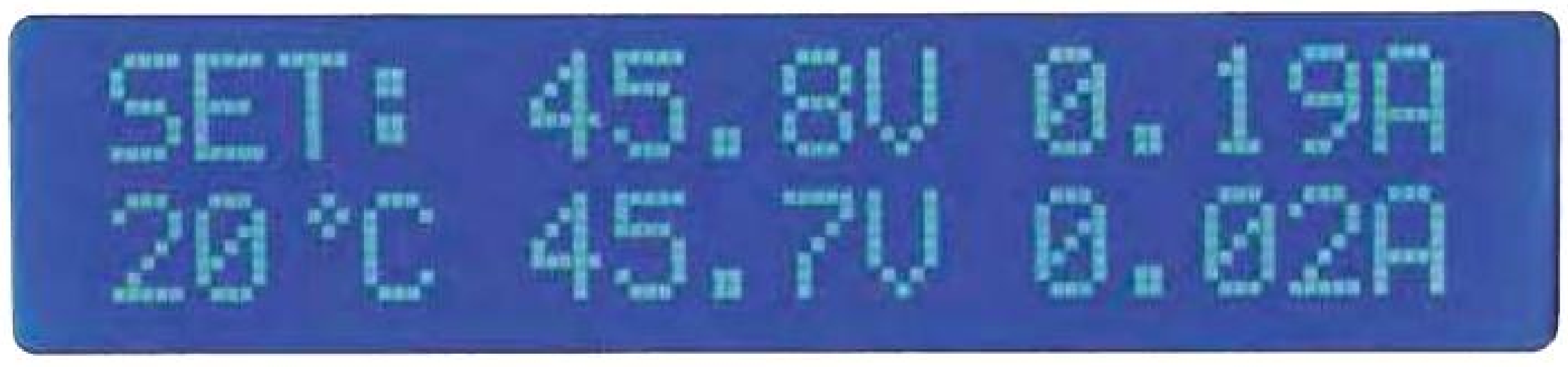


When configured as a *Panel Meter*, the display should look like this, with voltage, current and temperature readings. If using it as a *USB Display*, the screen will be blank until it receives data from the PC via its USB serial port.

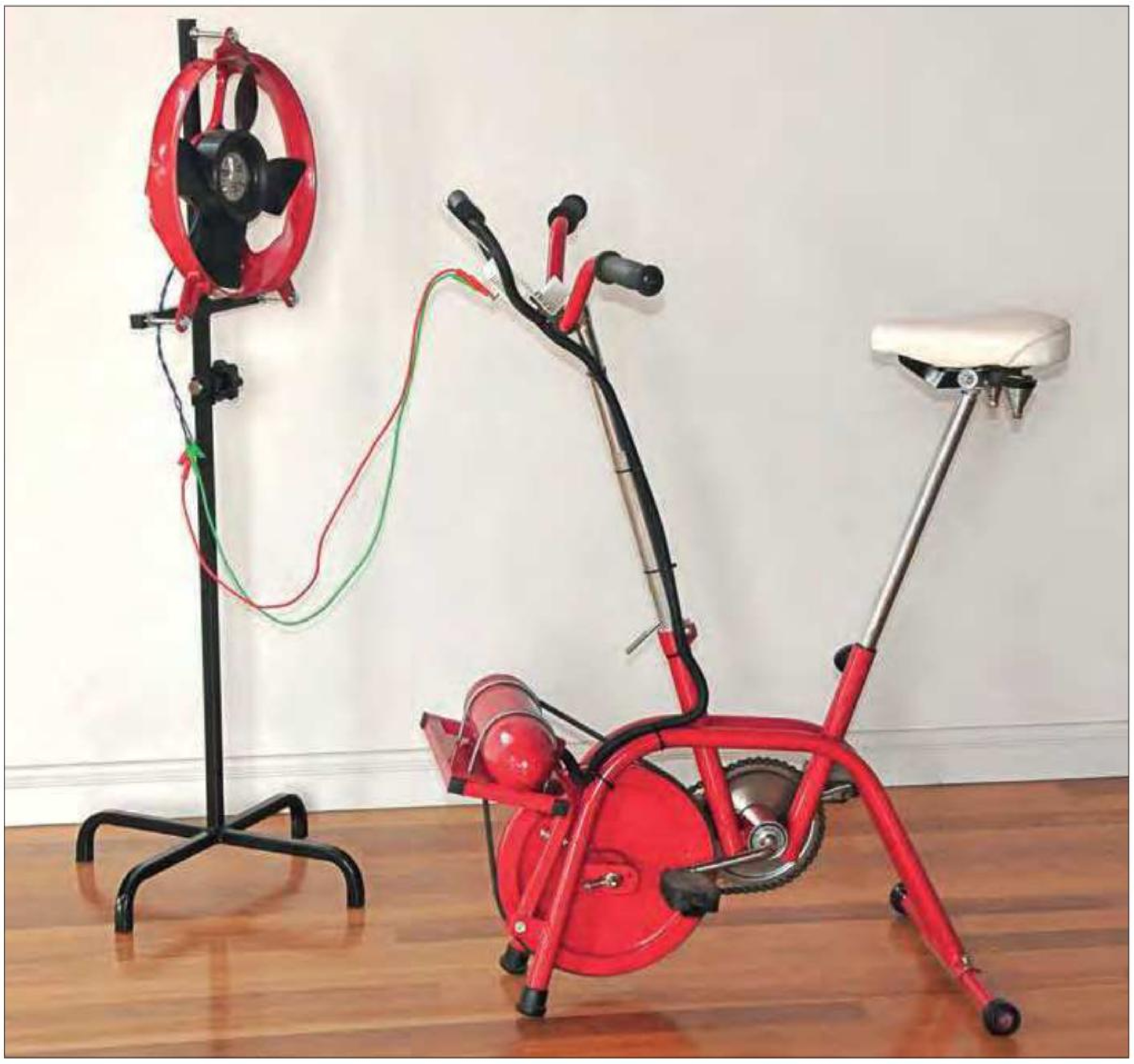
Pedal Power Station!

Part 2

Words and design: Julian Edgar
Photos: Georgina Edgar

This project generates real power, keeps you fit and yet you can build it from scrap and salvaged parts at low cost. Last month, we developed the mechanical section of the pedal-powered DC generator. Now it's time to use electronics to add instruments and condition the power output.

So, you've built your Pedal Power Station – now, what loads can you drive with it? The options are numerous, as we'll explain below. But before we get into the details, first a quick warning. Depending on the direction that you are driving the generator, the polarisation of the connecting leads may have changed over the original 'motor' orientation. For example, red might now be negative and black, positive. Therefore, before connecting any loads, always check the generator's output polarity with a meter and then label the leads accordingly.



If the *Pedal Power Station* is being used primarily as an exercise bike, a car radiator fan makes an excellent load. The fan has been mounted on an adjustable stand made from steel tube. In hot climates, the fan can cool you as you pedal!

Resistive loads

We'll start with the simplest load; just a resistor (and here of course, motor output polarity doesn't matter). The power rating of the resistor will need to be high (as in, hundreds of watts) and the resistance very low. On the machine shown opposite, best results came from using a 0.9Ω resistor.

The easiest way of obtaining such a resistor is to make one from galvanised steel wire of the type often used in gardening and fence repair. You will need to use thin wire, say 0.7mm diameter. To start, select a length that gives a measured resistance of about 1Ω checked via your DVM (do make sure your DVM is genuinely accurate in the single-ohm range). Form the resistor by wrapping the wire around a small diameter tube to shape it into a spiral, remove it from the tube and then bend each end into a small loop. Then use screws, washers, nuts and eye terminals to make the electrical attachments to the looped ends (you cannot easily solder directly to the steel wire).

Be careful when testing – the resistor I made could glow red-hot if I pedalled hard enough. If the resistor does get too hot, use a longer length of thinner wire.

A simple way of varying the resistor rating is shown in Fig.1. Minimum load occurs with both switches open, medium load with switch 2 closed, and maximum load with switch 1 closed. If the *Pedal Power Station* is being used as an exercise bike, this circuit therefore gives a variety of different pedalling efforts. The 'resistor' can be three resistors (or more) connected in series, or you can make one long resistor and simply take tappings along its length. Again, do remember that it can get hot, so ensure it is mounted safely away from you, small people's fingers and inquisitive pets.

PWM output control

If you want infinitely adjustable control of the load, you can use a DC variable PWM controller and the aforesaid resistor (or the other loads covered in a moment) – see Fig.2. These PWM

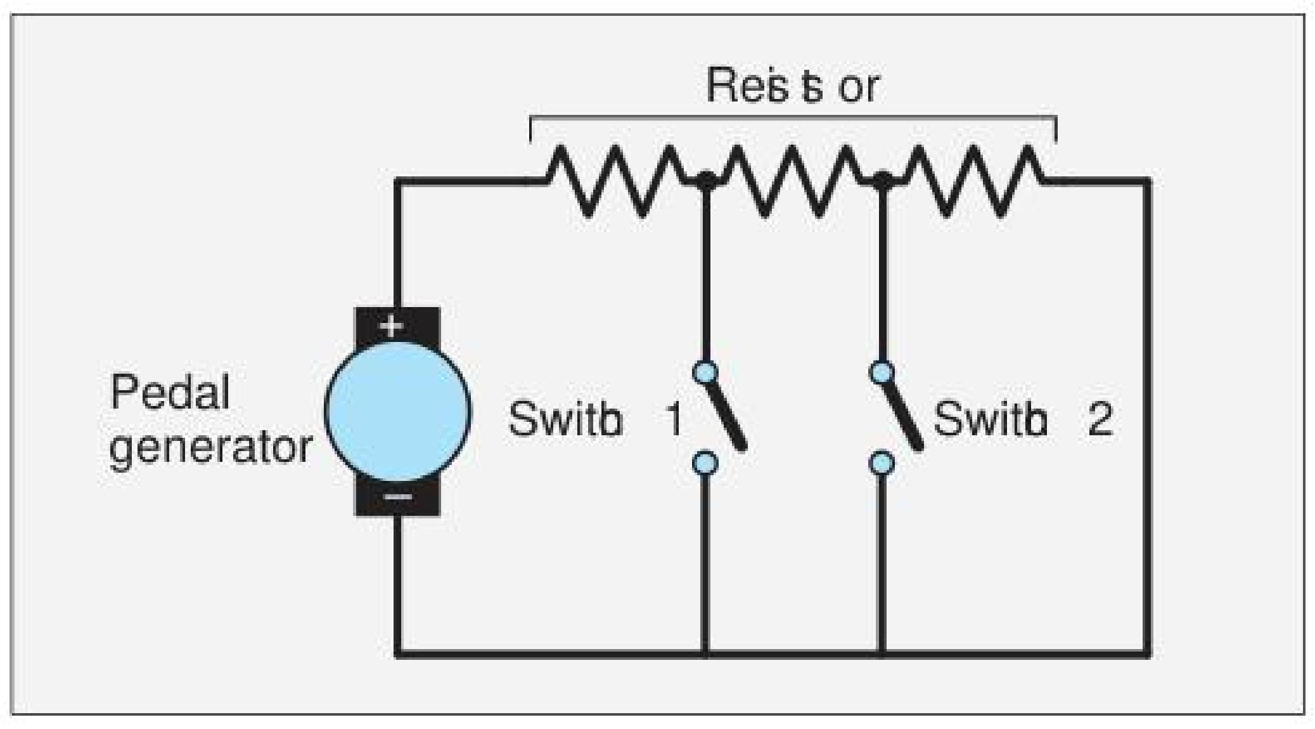


Fig.1. Using a multi-tap high-power resistor (that you can easily make yourself) and two switches allows adjustment of load when the *Pedal Power Station* is being used as an exercise bike. Here, minimum load occurs with both switches open, medium load with switch 2 closed, and maximum load with switch 1 closed.

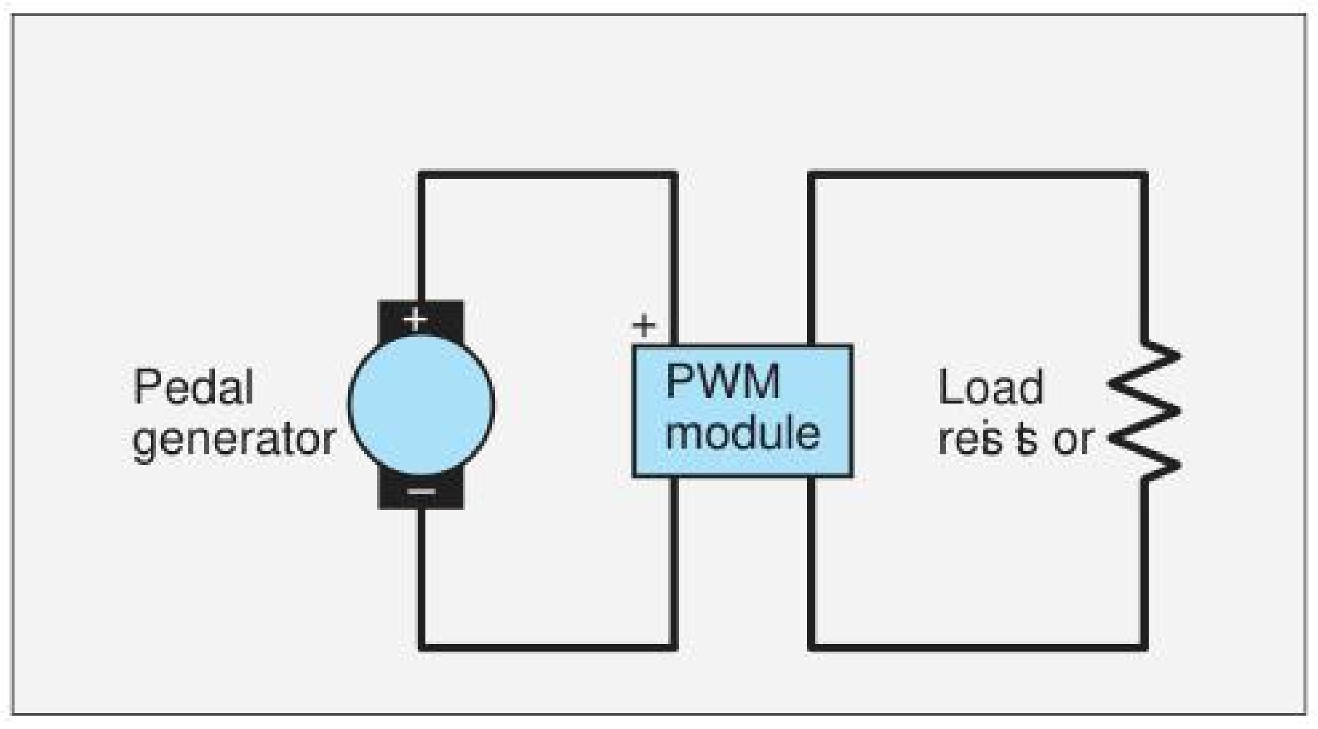


Fig.2. A PWM module (often sold online as a 'DC motor speed controller' or similar) allows stepless adjustment of load at the turn of a knob. Ensure you buy a PWM module that has the required current rating.

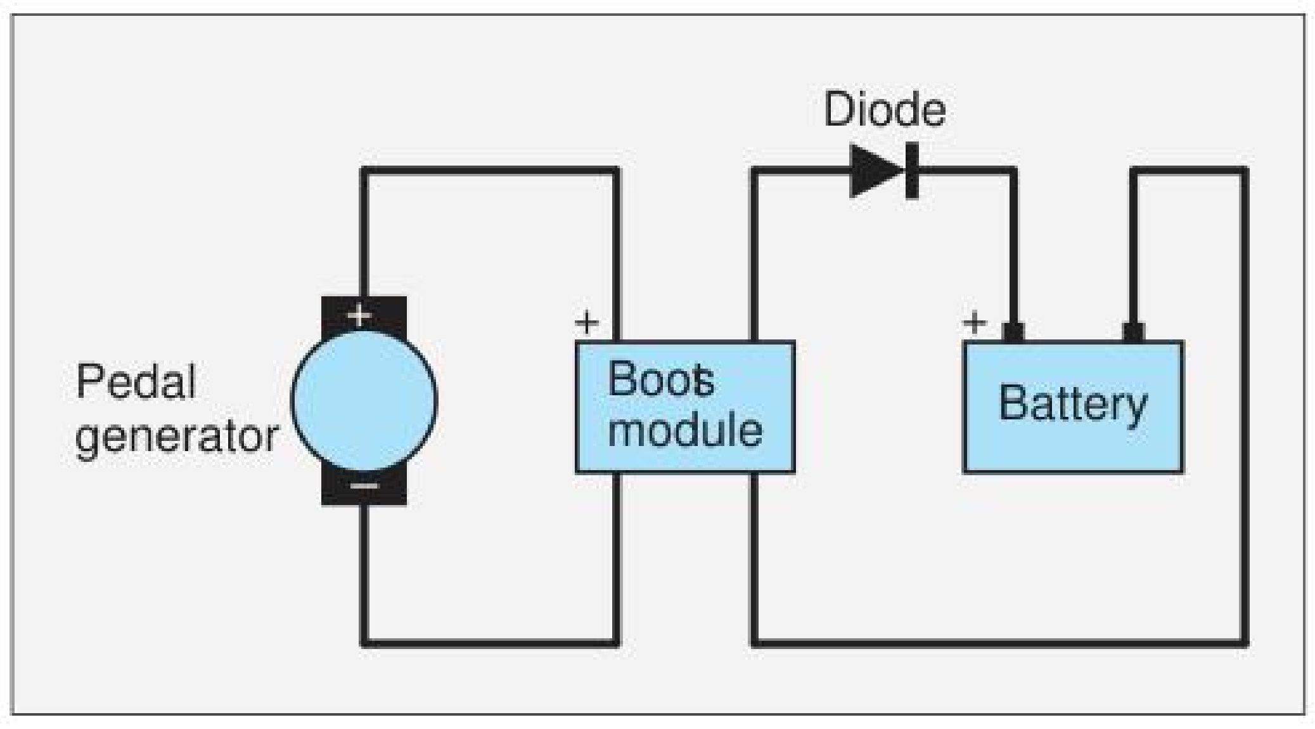


Fig.3. A constant voltage boost module can be used to electronically 'gear-up' the *Pedal Power Station*. For example, here the boost module has been used to increase output voltage to allow the charging of a 12V lead-acid battery. Note the required diode – boost modules don't like having battery voltage applied to their output!

modules are often sold on eBay as 'DC motor speed controllers' or similar.

I tested the module I reviewed back in the May 2016 edition of *PE/EPE* on the pedal generator. This module has an input voltage of 6-28V and a maximum current of 3A. As you'd expect with this relatively low current rating, it was easy to get the module rather hot! However, this module, which is very cheap, would be quite suitable for a lower-powered pedal generator. To my surprise this item (or one very similar) is still available – at the time of writing eBay item 233664457658. Higher current PWM controllers are also readily available, for example eBay item 124329447989 has a claimed rating of 8A.

Hunt around on all the usual websites (eBay, Amazon, Banggood, AliExpress…) for something along the lines of 'Variable PWM power module'.

Lights

Much more exciting than driving a resistor is to illuminate an appropriate number of LEDs or incandescent lights.

Depending on the power output of the generator, you may be able to drive strings of literally hundreds of LEDs. Be careful that even the hardest pedalling cannot exceed the rated voltage of the LED strings (or alternatively, drive the LEDs via a constant current converter).

Incandescent lamps are a really 'rewarding' load to drive. For example, multiple 50W headlight bulbs are both very bright and alter in level in a most satisfying way with pedalling effort. Unlike LEDs, you can also *briefly* over-drive incandescent bulbs without damage. For a fun demonstration of the power available from pedalling, lights are best.

Fan

Another really rewarding load to drive is a 12V car radiator fan. These are available quite cheaply from car dismantlers and people selling car parts.

These fans will usually start turning at a quite low voltage (eg, 3V) and the load they provide goes up rapidly with speed. Therefore, this load is – just like incandescent lights – effective for a variety of people. Even a child pedalling gently will get the fan to spin, while a strong person pedalling hard will generate a gale!

In hot weather, using a fan as the load also has the benefit of cooling the rider – ideal when the machine is being used as an exercise bike.

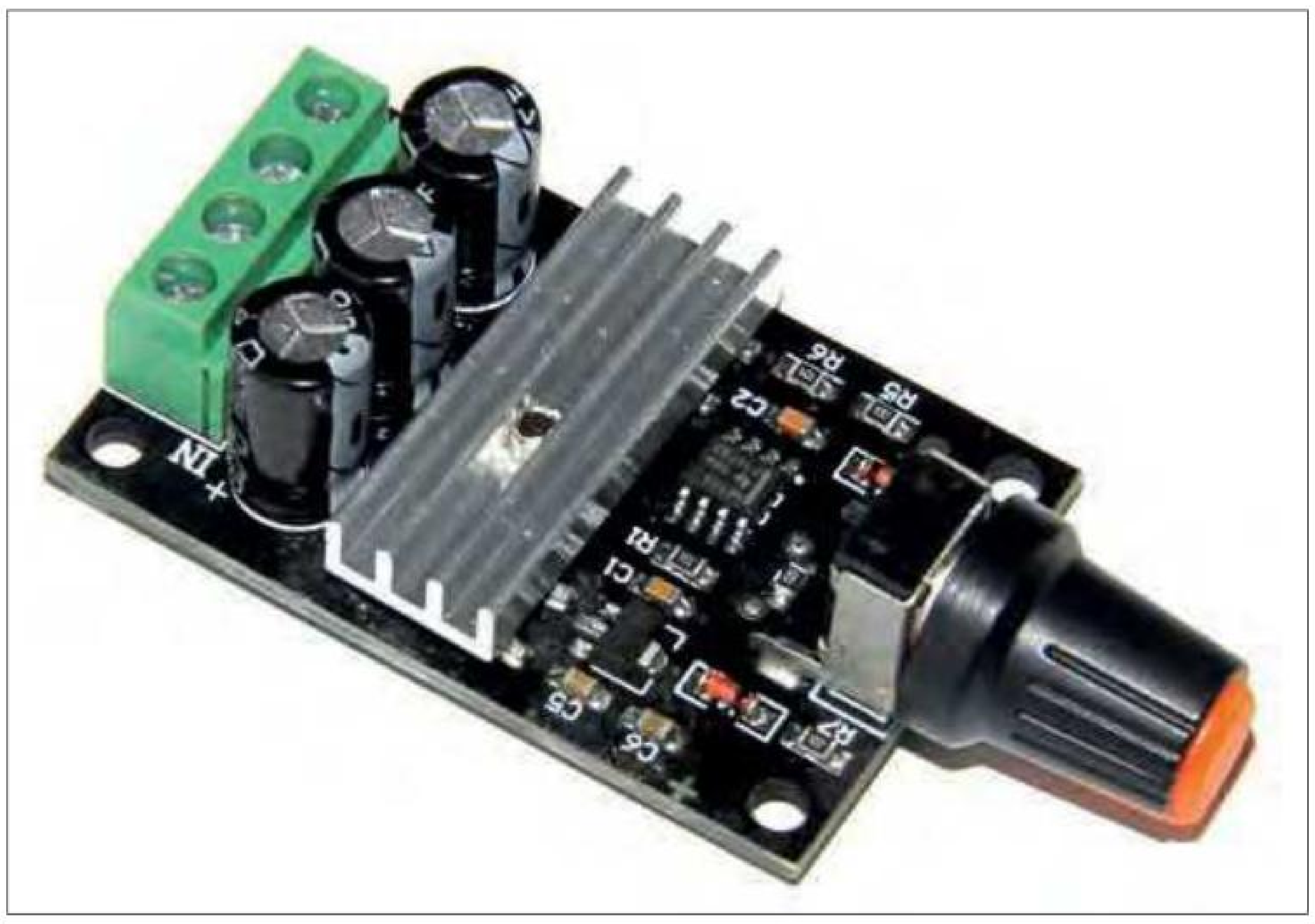
USB car chargers

Commonly available and cheap, 12-24V USB 5V chargers can be used with even a small DC generator. These chargers are specified for a maximum of 24V, so it is less likely you will exceed their rated input voltage (but of course always check the maximum no-load voltage output of the generator). The small current these chargers draw means that charging even multiple phones will take little pedalling effort – another great educational demonstration of pedal power.

Battery charging

The *Pedal Power Station* can be used to charge standalone batteries. Best results will usually come from using a dedicated charger module designed for the specific battery type. For example, an 18650 li-ion car charger with a 12-24V input is suitable for most pedal generators.

Two screw terminals have been mounted on a box to provide the power output connections.



For lower-power generators, a PWM module like this one allows you to adjust the output power (and hence pedalling load). Similar higher-current PWM modules are readily available.

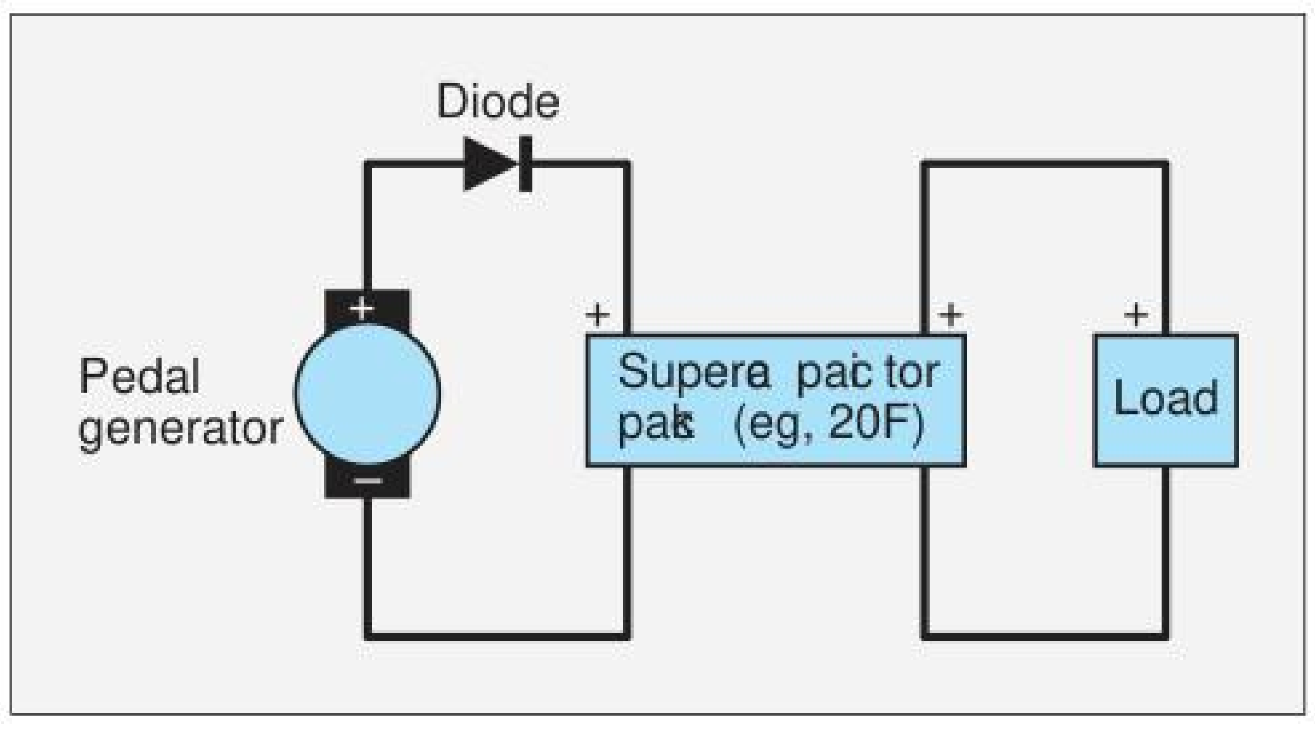


Fig.4. An 'electronic flywheel' effect is achieved by using a supercapacitor pack to smooth the generator's output. Here a large 20F unit has been used, but depending on the load, you may be able to use a smaller (and cheaper) 1F pack. The diode prevents the supercapacitor pack from driving the generator as a motor when you stop pedalling.

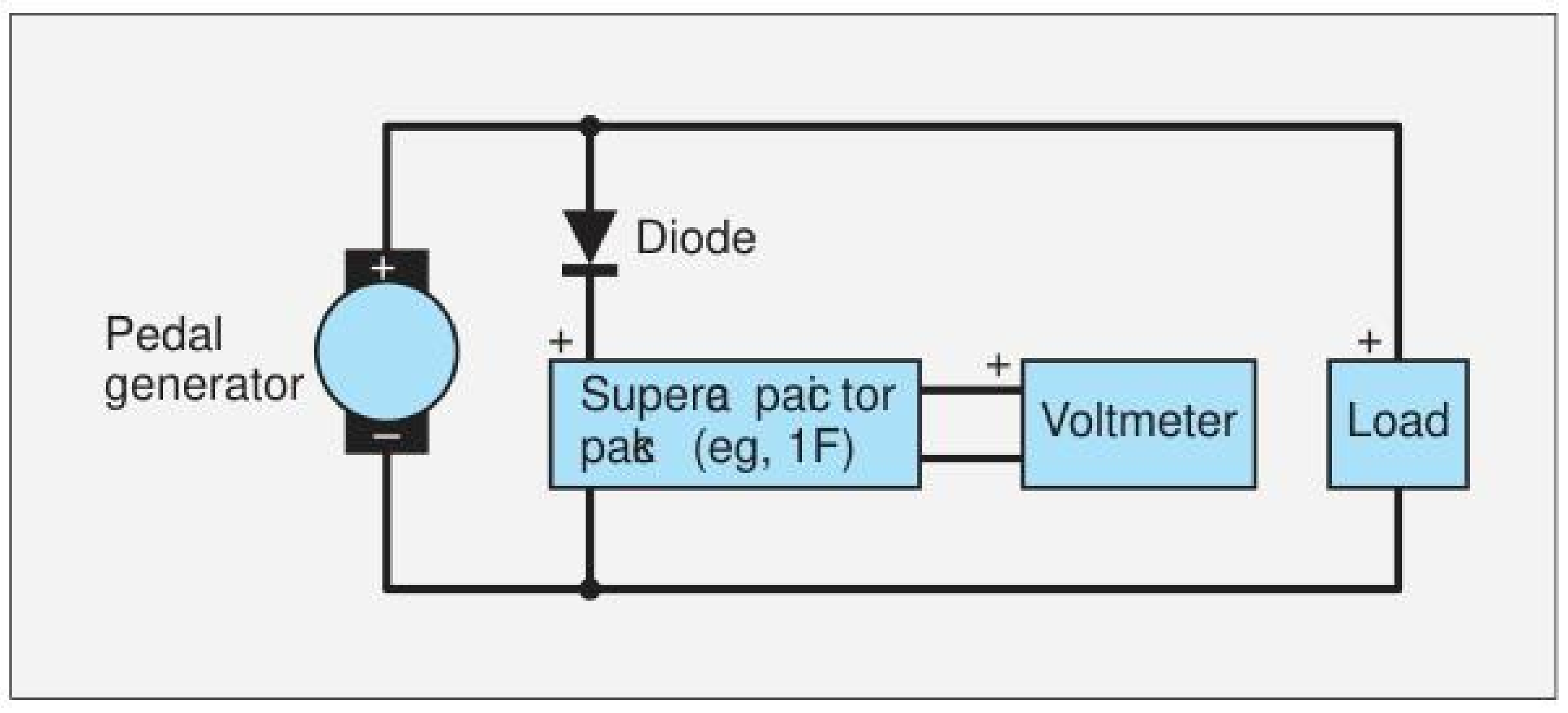


Fig.5. A 2-wire voltmeter is a simple way of monitoring output. However, you may find that the display 'dances around' a lot with the slight variation in voltage that occurs as you pedal. Here, a 1F supercapacitor pack has been used to give the voltmeter a long time constant, stabilising the display.

Boosting the voltage output

Constant voltage boost converters are an ideal match with the *Pedal Power Station*. Taking this approach allows you to electronically 'gear' the generator higher than achieved through mechanical means.

For example, at a moderate pedalling speed, the *Pedal Power Station* shown on these pages had a no-load output of about 13V. That sounds like enough to charge a 12V lead acid battery, but by the time you add the voltage drop of a series diode, the resulting voltage is just a little low for charging. However, if you add the boost converter and set it to say 14.5V (that takes into account the diode voltage drop) and you'll have a practical charging machine.

To find these boost converters, search eBay under 'DC-DC Boost Converter Power Module'.

Note that if using a boost converter to charge a battery, you must use the series diode between the converter and battery – some of these converters will be destroyed if the battery voltage is applied directly to their output. Fig.3 shows the essentials of the set-up, but do undertake further research if you are new to this topic.

Smoothing the output

If the pedal machine has only a light flywheel, the electrical output of the generator is likely to noticeably vary with each pedal stroke. If you are driving lights, for example, this can be annoying as the lights alternately brighten and then dim.

To overcome this, the output can be electrically smoothed by using a supercapacitor pack. Feed the pack through a diode (otherwise the supercaps will drive the generator as a motor when you stop pedalling!) and then feed the load from the supercap pack. Remember to observe correct polarity and ensure that the voltage rating of the pack cannot be exceeded – refer to Fig.4.

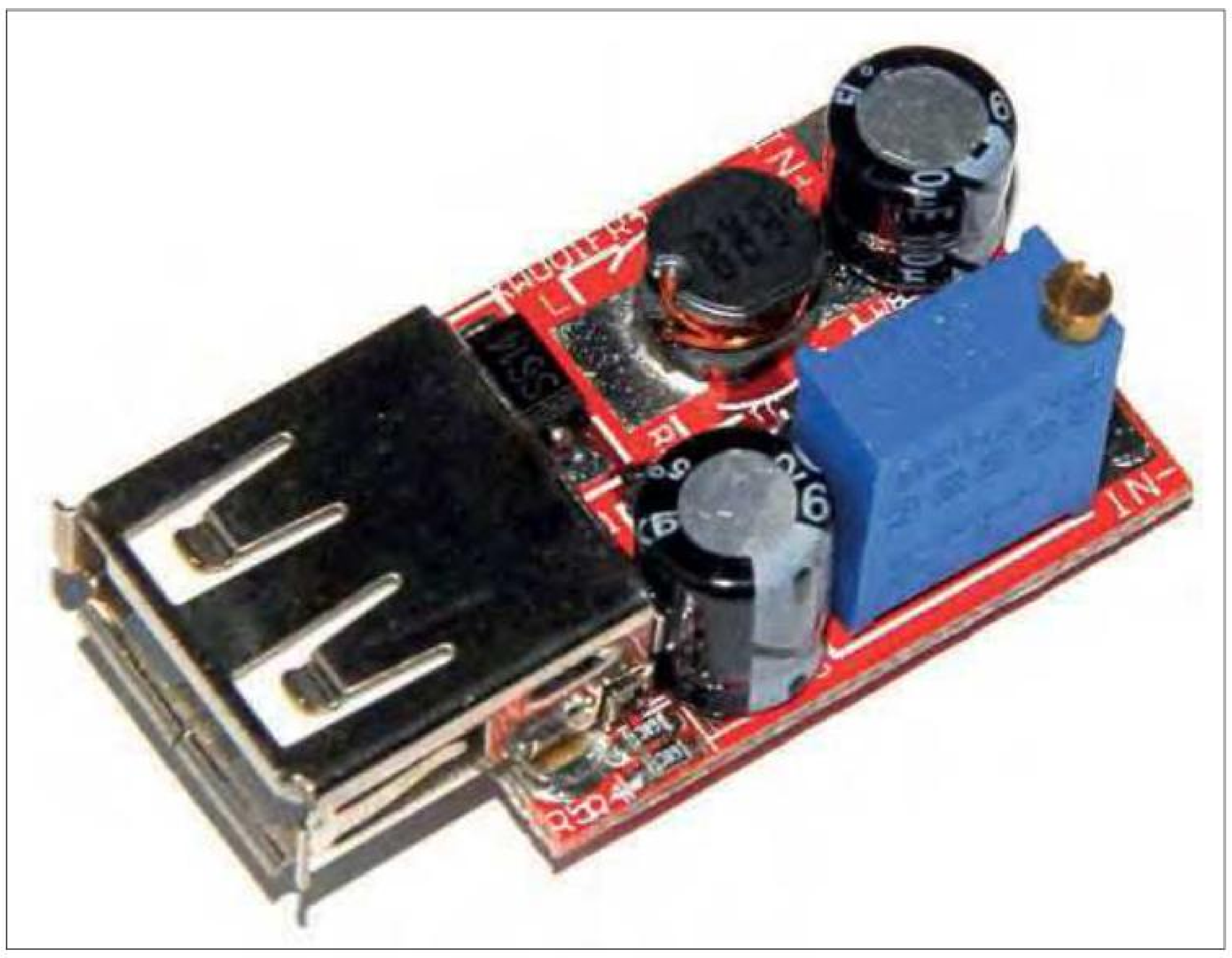
I used a 20F (yes, twenty farads!), 16V supercapacitor module, one that incorporates charge-equalisation circuitry. This worked well in smoothing the output, with the minor downside that when first starting to pedal, the effort was higher while the supercaps initially charged. To find similar modules, search eBay under '16V 20F Ultracapacitor Engine Battery Starter Booster Car Super Capacitor' or similar.

Instrumentation

There is a wide range of instruments you can fit to the *Pedal Power Station*.

A digital 2-wire DC voltmeter is cheap and easy. These are available from eBay from only a few pounds and some are available that will work from 5-120V DC – just connect the voltmeter directly to the generator's output.

Alternatively, an LM3914-based bar-graph display can be used – these are also available on eBay and have adjustment pots to allow the high and low voltages to be individually set. (Search under 'LM3914 Battery Capacity Indicator Module LED Power Level Tester Display Board' or similar) These display boards are suitable for voltages up to 20V and cost only a little more than the LED voltmeter.



Charging of phones and other equipment that uses USB 5V charging is easily achieved with a charging module like this. Ensure the module is rated for the maximum voltage the *Pedal Power Station* can produce off-load.

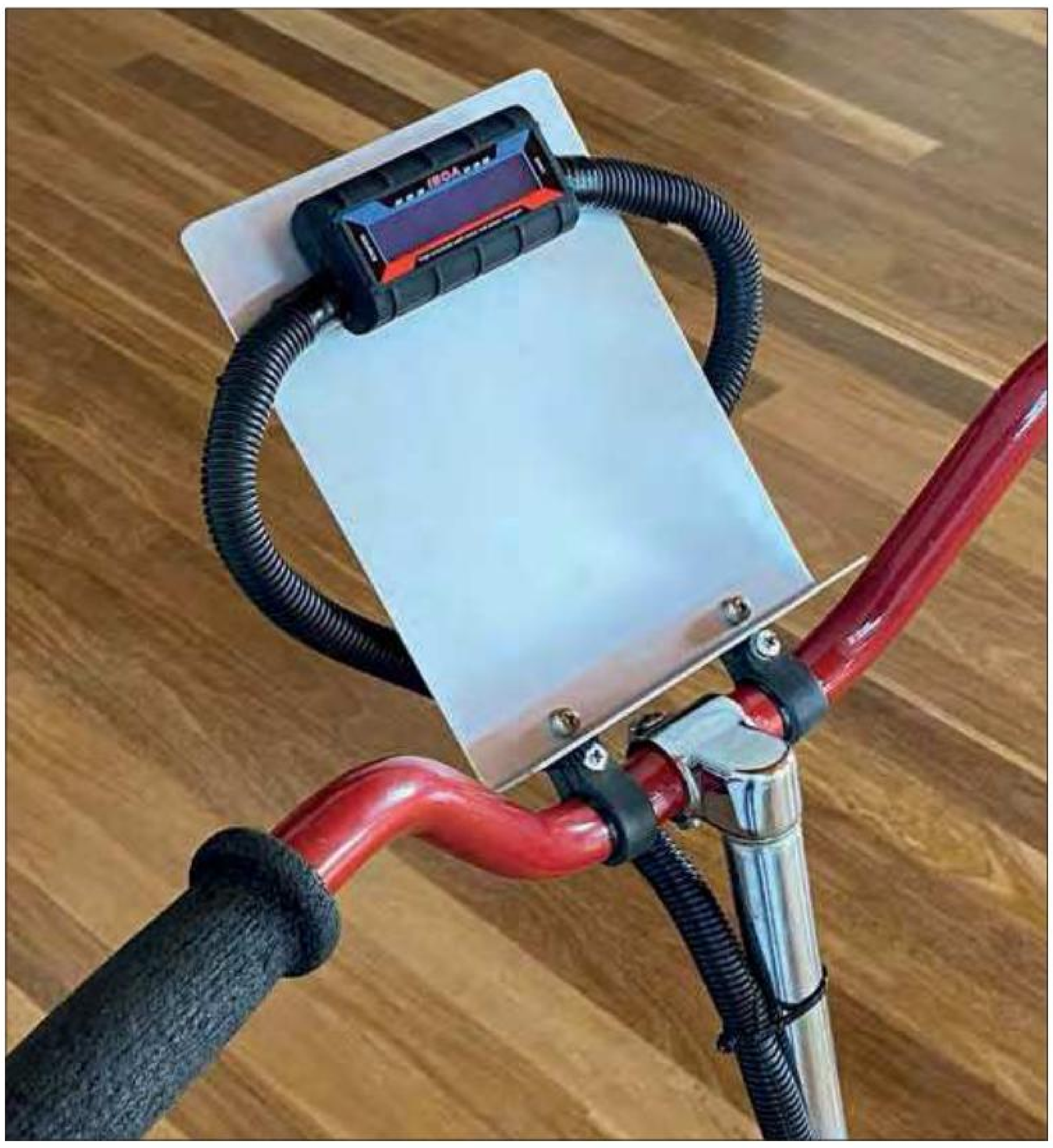
A supercapacitor pack can be used to smooth the power output. This is a 20F 16V module that incorporates charge equalisation. Feed the supercapacitor pack from the generator via a diode, and be careful to observe correct polarity.

A 20A boost-voltage converter like this is highly effective with the *Pedal Power Station*. For example, it allows constant voltage charging of a 12V battery, even if the generator's 'raw' output is a little too low in voltage to charge the battery.

You may find that a voltmeter display 'dances around' as your pedalling output varies. You can use a capacitor across the voltmeter input to settle its reading. For example, Fig.5 shows an LED two-wire voltmeter with a 16V 1F supercapacitor pack – you don't have to use the (more expensive) 20F supercapacitor pack mentioned above. The 1F pack gives a long time constant for the display – and as a bonus, the LEDs stay alight for about five minutes after you stop pedalling. (If the load you are driving has a very low resistance, you may need to add a series resistor after the diode – this will slow both the charge and discharge rates of the supercapacitor pack).

How much power?

More sophisticated than a voltmeter – but also more expensive – is an LCD instrument that displays measured voltage and current, and from these calculates power. After testing a few different modules, the best I found is a device that is low in cost, uses a two-line back-lit LCD and can measure a wide variety of parameters. You can find it by searching online under '150A Digital LCD Watt Meter Power Analyser Solar Caravan Anderson Plug Tool' or similar. At the time of witing, for example, eBay item 402438984452. It costs around £10 delivered – check the pictures below to ensure you select the correct module.



Here an LCD power meter has been fitted. This meter is powered by the bike itself and displays a variety of parameters, including peak and average power. Its mount (made from folded aluminium sheet) also provides a rest for a smart phone below the meter, allowing the rider to be entertained as they ride. Add a USB charger and you can even charge your phone while you exercise.

If the exercise bike develops an output of more than 8V under load, this meter can be powered directly from the bike generator. (You can apparently also power the meter from a separate battery, but I didn't do so.) Connections are very simple – the heavy cables on the 'source' side of the module connect to the generator, and those on the 'load' side connect to, yes, the load! Maintain the correct polarity when making both these connections. The device is supplied with Anderson-type plugs, but I found it easiest to cut these off and connect directly to the flying leads.

So, what is displayed? The LCD shows two types of data – some shown continuously, and some cycling through different parameters. Shown continuously are amps (maximum of 150A, with a resolution of 0.01A), volts (maximum of 60V with 0.01V resolution) and watts (maximum of about 1600W with a resolution of 0.1W). The bottom-left display cycles through the following in turn: Ah (amp-hours), Wh (watt-hours), Ap (peak amps), Wp (peak watts).

This line-up of data allows you to measure almost every parameter you're interested in – whether you're charging a battery or having a competition as to who can generate the most pedal power! Note that unless you use an extra battery to power the display, all peak data is lost as soon as you stop pedalling.

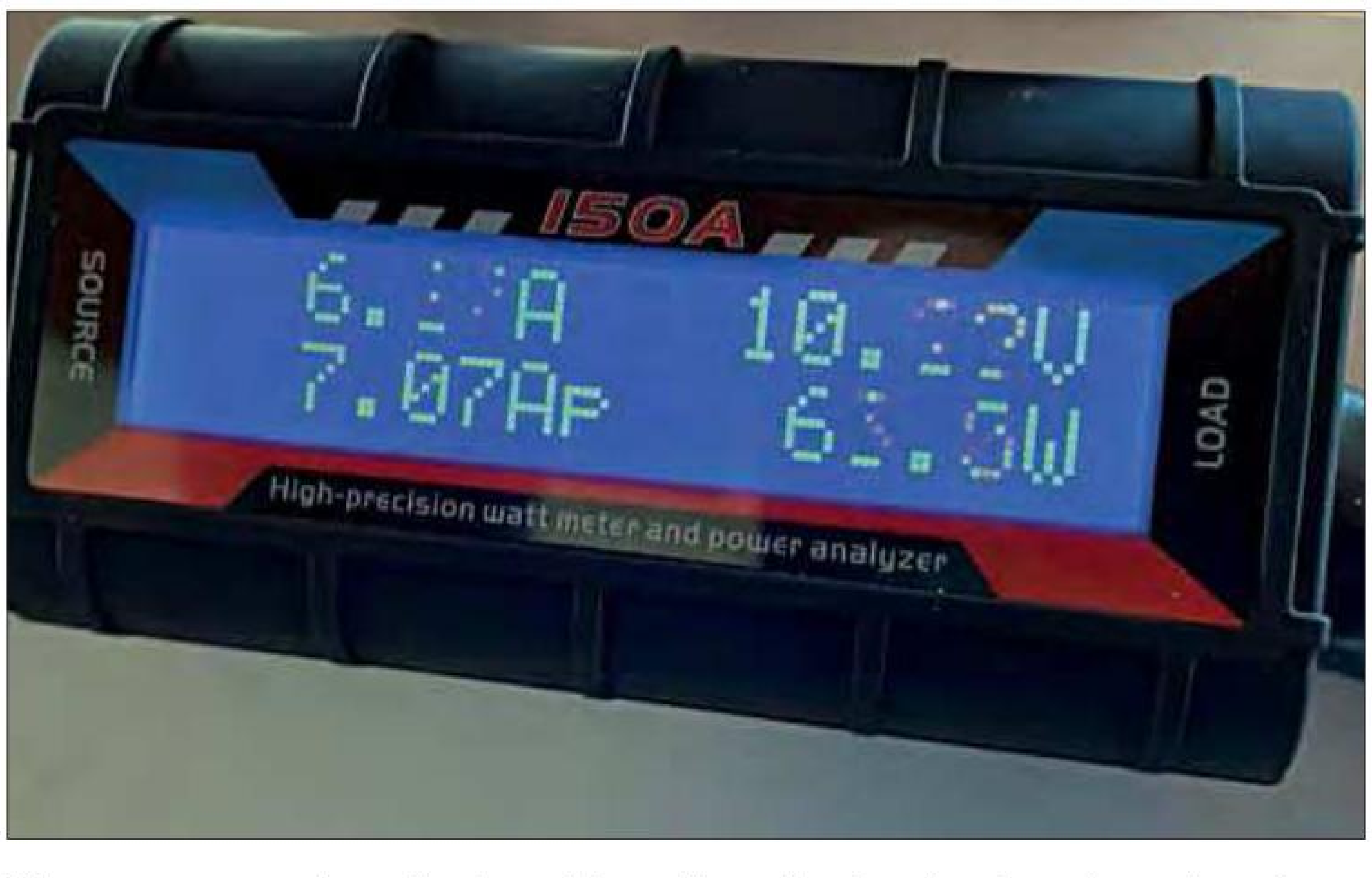
Conclusion

I'm very happy with how this project turned put. The V-belt drive is as smooth as silk, and everyone who has seen the *Pedal Power Station* in action has wanted to ride it. The use of low-cost, pre-built electronics also allows the charging of batteries or powering of lights in ways that previously were difficult and/or expensive to achieve with pedal generators.

Used as an exercise bike, a PWM module allows stepless load changes – or alternatively, the machine can be electrically simple, with multiple load pre-sets achieved just by switching in different home-made resistances.

Instrumentation can be as simple or complex as you want, with even a sophisticated digital instrumentation display that is low in cost.

All you need to do now is keep an eye out for discarded exercise bikes and heavy-duty DC motors!



The power meter display. Here the display is showing about 6A, 10V, a peak current of 7A and a power of 63W. The display costs around £10 delivered and is powered by the bike's generator. (The odd-looking digits are an artefact of the camera shutter speed.)

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 22: A modern-style analogue GPS clock

Last month, we explored how to connect your *Micromite Keyring Computer* (*MKC*) to a GPS module, and enable them to communicate with each other via the UART protocol. With just a few lines of program code we were able to extract the highly accurate time information contained within a GPS 'sentence', and format it for display on your computer's terminal app screen. This month, we want to use this accurate GPS time data and display it on a dedicated display, allowing the creation of a standalone gadget, free from being tethered to your computer. We could have simply displayed the time information in the usual digital format on one of the several screens that we discussed earlier in the series, such as the mini-IPS screen, or the larger 2.8-inch TFT touchscreen. However, we wanted to set ourselves a challenge and see if we could do things a little differently by displaying the time in the more traditional analogue format.

To avoid anything mechanical, it seemed logical to base the display hardware on a ring of 60 RGB LEDs. Having 60 RGB LEDs in a circle means that each LED can represent a minute on an analogue clock. We can then use three different coloured LED 'dots' to represent the positions of the three 'clock hands' (hours, minutes, and seconds). This gives a traditional analogue clock a nice modern twist; however, it turned out that the three coloured 'dots' were not quite suitable for displaying the time as we will now discuss.

Dot-Dot-Dot

Fig.2 shows the original concept of using three different coloured LEDs (dots) to represent the three clock hands. Here, blue represents hours, green represents minutes and red represents seconds. So, the time shown in Fig.2a is 10:13:43. The white dots are the hour markers (or five-minute markers) as usually found on most analogue clocks – and are simply there to help make it easier to read the displayed time. Note that the top-most marker at the 12:00 position is brighter than the other markers to help orient the clock.

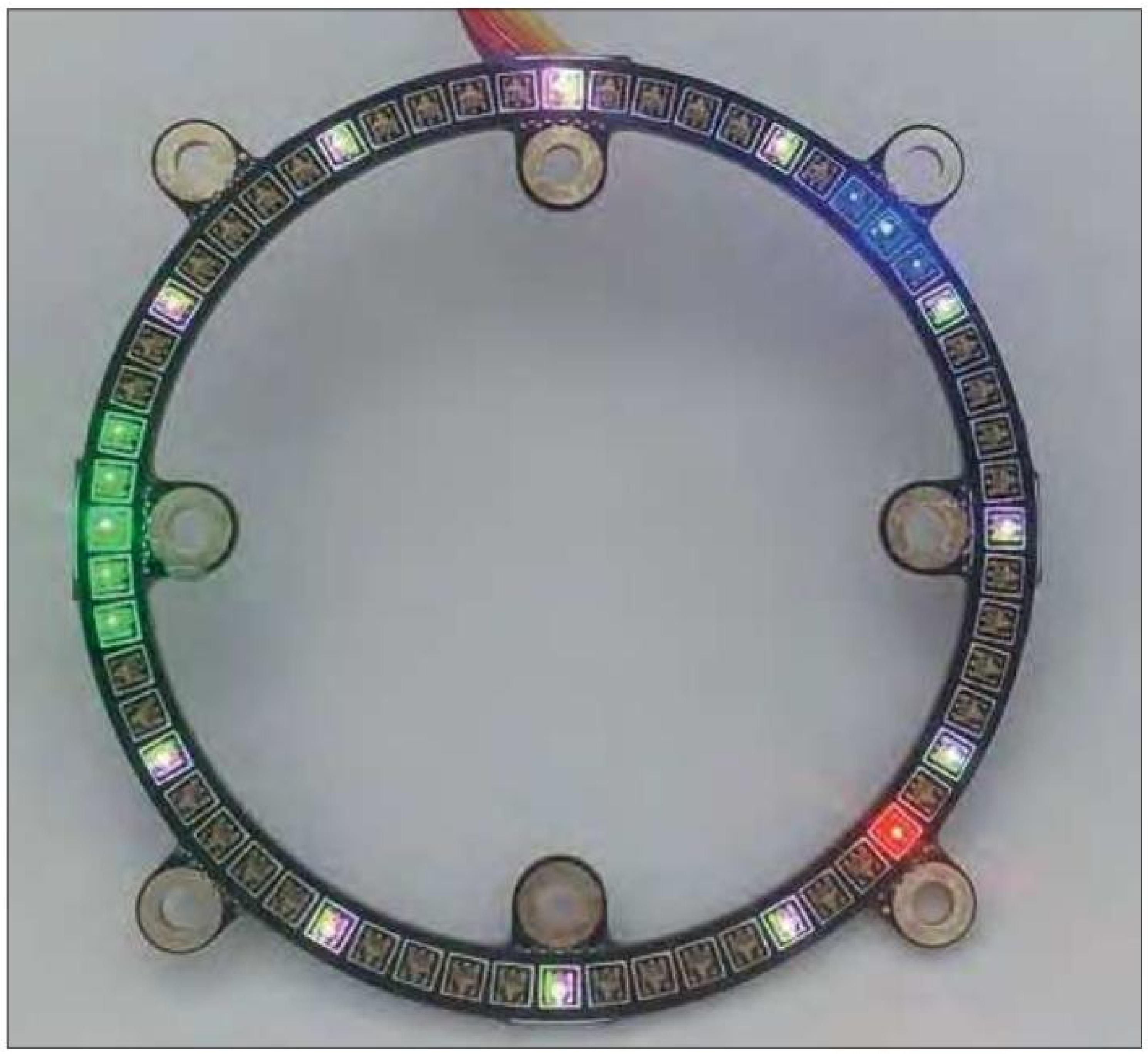


Fig.1. This analogue GPS-based clock uses a ring of 60 RGB LEDs, producing a modern twist on a classic format.

So, what exactly is the problem with using three coloured dots to represent the three clock hands? Well, most of the time there is no issue at all since the three dots will be in different positions to each other. However, as the seconds dot (red) moves around the clock ring, at some stage it will be in exactly the same position as the minute dot (green), or perhaps the same position as the hours dot (blue). Likewise, the minutes dot could be in the same position as the hours dot.

The result is that you would just see two dots; for example, when the time is 01:05:22 meaning that the hour dot and the minute dot would be in the same position. Similarly, just a single dot might be seen; for example, when the time is 12:00:00.

In the above scenarios, the resultant colour of the one, or two dot(s) would be determined by the sequence in which they are 'drawn' to the RGB ring. In our code we have specifically drawn the twelve markers first, followed by the minutes dot (green), then the hours dot (blue), then the seconds dot (red) last – the reason why we chose this sequence will be explained later.

Let's focus on the time 01:05:22. Our code ensures that of the three hands, the green minutes dot is drawn first (at the 5-minute marker), then the blue hours dot is drawn at the 1-hour marker, effectively overwriting the green dot. Finally, the red seconds dot is drawn in the relevant position. The result is one blue dot in the 5th position, and one red dot in the 22nd position – see Fig.2b.

In fact, for the whole minute of the time 01:05, the green (minutes) dot is not displayed as it is always overwritten by the blue (hours) dot. Also note that at exactly 01:05:05, only the red (seconds) dot would be visible for one whole second – see Fig.2c.

The conclusion is that the 'three coloured dots' method sometimes makes

Micromite code

The code in this article is available for download from the *PE* website.

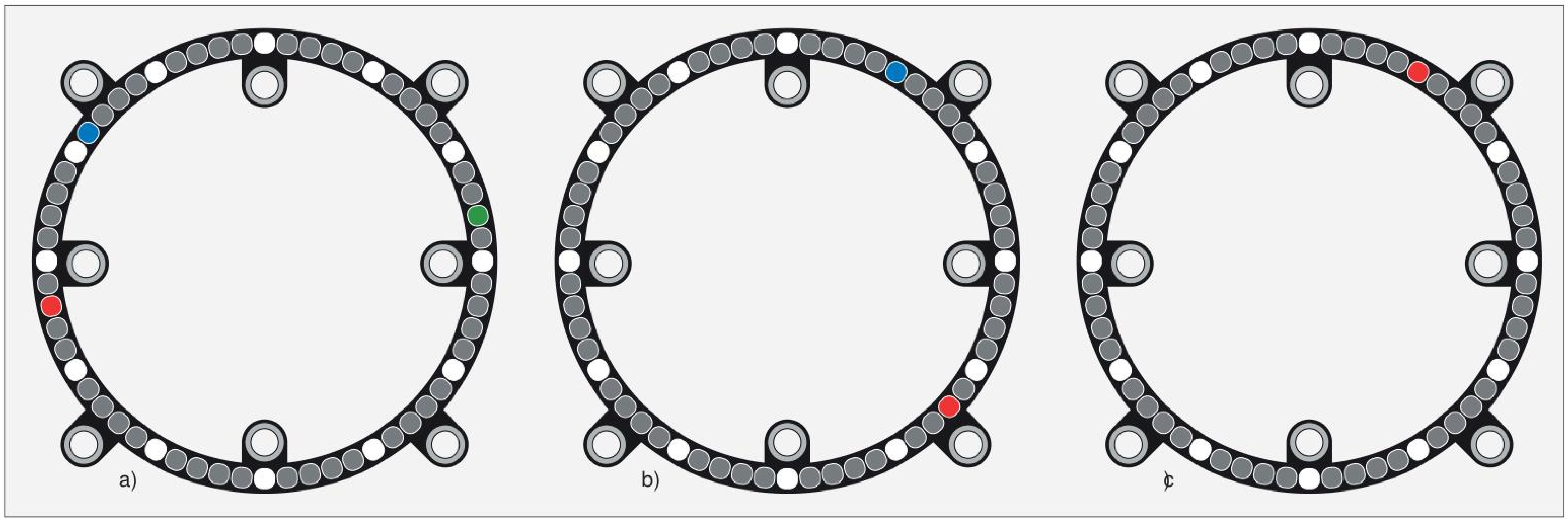


Fig.2a. Knowing which colour represents which clock hand allows the time to be read – here 10:13:43. Fig.2b. In this example of 01:05:22, the minutes dot (green) is overwritten by the hours dot (blue) resulting in just the blue hours dot and the red seconds dot being visible. Fig.2c. At 01:05:05, only the red seconds dot is visible because all three 'dots' fall in the same position on the clock ring.

it difficult to read the time; hence we need a way to resolve this.

Dot-Dash-Dash

On a normal analogue clock, the hours hand is physically shorter than the (bigger) minutes hand. Therefore, when they are aligned, you can still see both of them even though they are in the same position. We will use this concept to resolve our 'three dots issue' by representing the hours hand as a smaller 'dash' of three adjacent blue dots, and the minutes hand as a bigger 'dash' of five adjacent green dots. The red seconds hand remains as a single dot and the end result is shown in FIg.1 and Fig.3. At first glance it may look confusing; however, remember that the big (green) dash represents minutes and the smaller (blue) dash represents hours, then it does become easy to read the time.

There are three points to note regarding the dashes:

1. The central LED in a dash is much brighter than the other LEDs in the dash. Therefore, the dash can be considered as a dot with an 'illuminated shadow'.
2. The green minutes dash has two shadow LEDs on either side of the central bright green LED. The shadow LEDs furthest away from the central dot are dimmer than the two shadow LEDs immediately next to the central LED.
3. The central bright LED in a dash will overwrite a white marker; however, any 'shadow LED' in a dash is overwritten by the marker. This means that a marker is visible unless a hand falls exactly on the marker. Fig.4 shows an example of this for the time 07:09:28 in which a minutes shadow LED is behind the 10-minute marker.

Once again, let us consider the times 01:05:22 and 01:05:05 – these are both shown using the Dot-Dash-Dash method in Fig.3a and 3b respectively.

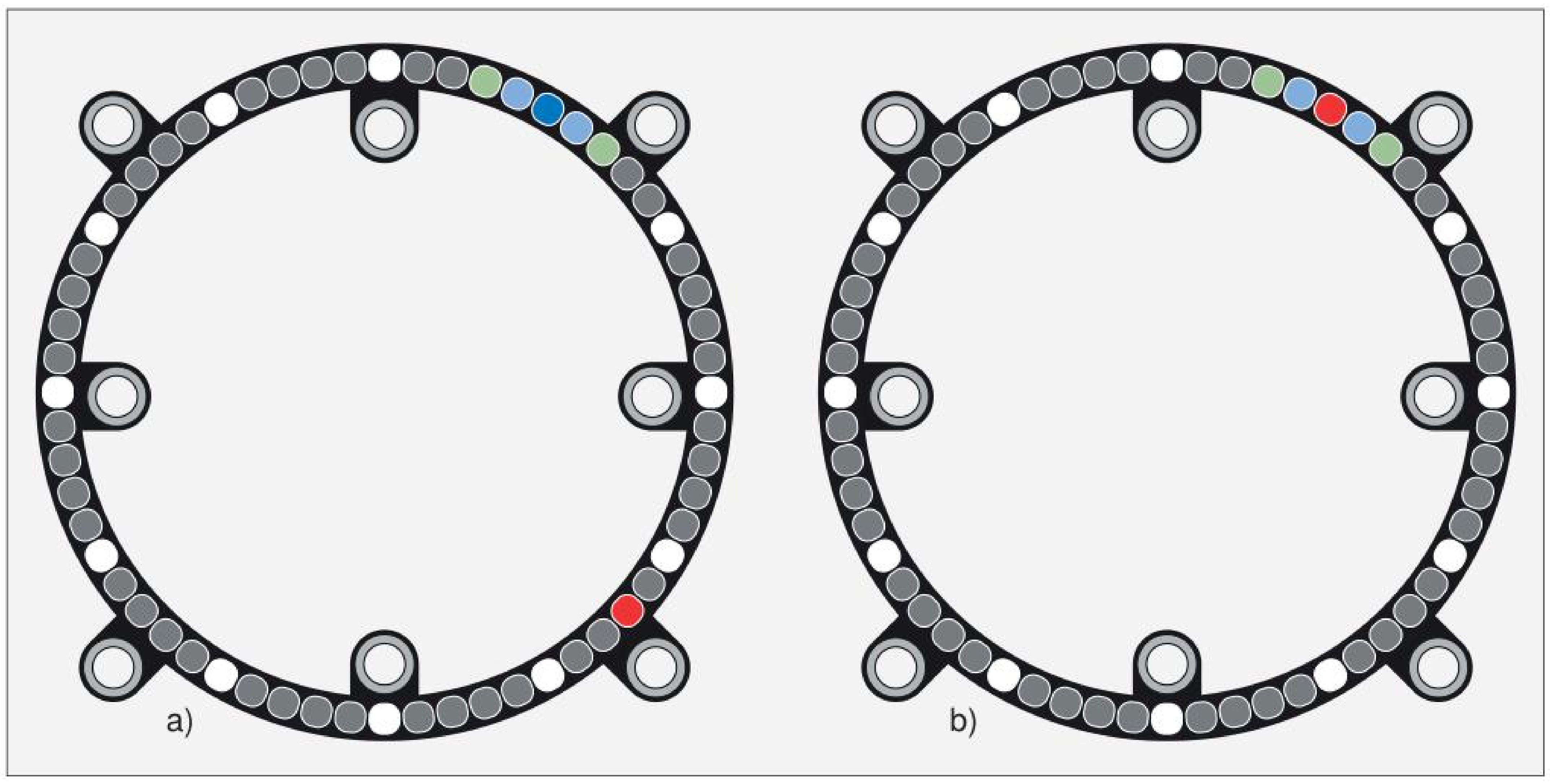


Fig.3. The bigger minutes hand (green) and the smaller hours hand (blue) make it much easier to read the time when the hands overlap since all three coloured hands can be seen no matter what the time is. In Fig.3a the time 01:05:22 and in Fig.3b it is 01:05:05.

Now that we have a concept for showing all three hands simultaneously, no matter what the time is, there is one more consideration to take into account in order for the time to be easily read. On a normal analogue clock, as the minute hand works through it's one revolution in an hour, the hour hand slowly progresses from one-hour marker to the next. For example, at half-past the hour, the hour hand sits halfway between the two relevant hour markers. We want to mimic that effect in our clock so we will describe how this is achieved shortly. First though, we will describe how we can conveniently control the 60 LEDs.

The RGB LED ring

Back in *Part 13* (*PE*, Feb 2020) we discussed how to control a strip of eight individual RGB LEDs (on a BlinkT module) by using just two SPI pins (Clock and Data). The specific type of RGB LED used in the BlinkT was the APA102, and these LEDs are perfect for easy control with a Micromite. As we saw back then, to control each individual LED we just need to send four bytes of data representing the brightness, and the red, green and blue intensity values that together define the overall colour of an LED. But our analogue clock requires sixty of these APA102 RGB LEDs (not just eight), with all sixty being arranged in a circle (and not a straight line). Thankfully, a ring of 60 × APA102 LEDs exists as a module and they can be purchased from many of the usual online suppliers. We sourced ours from Cool Components (no affiliation) and this particular ring comes in a compact 3-inch diameter (see photos). Be careful when you search online, some suppliers will sell at a price that at first seems relatively low, but this is for a 'quarter of a ring' and hence you will need four quarters to make the full ring. The most important point is that the total ring comprises 60 APA102 LEDs (other rings containing different quantities of LEDs do exist – so beware!).

The nice thing about the APA102 LED is that no matter how many of them you have connected to the Micromite (60 in this case), you can control the colour and the brightness of each individual LED by simply sending the appropriate quantity

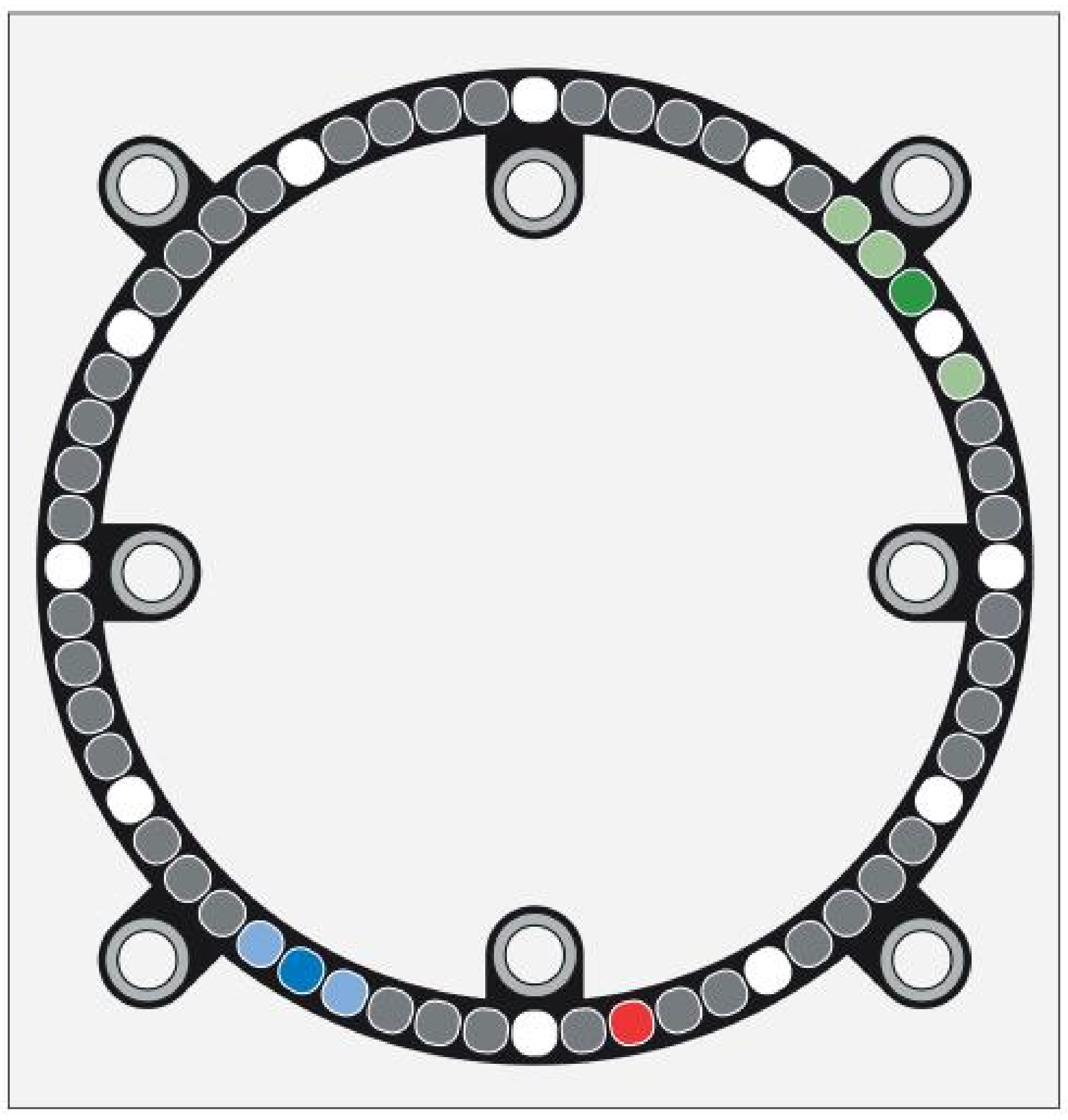
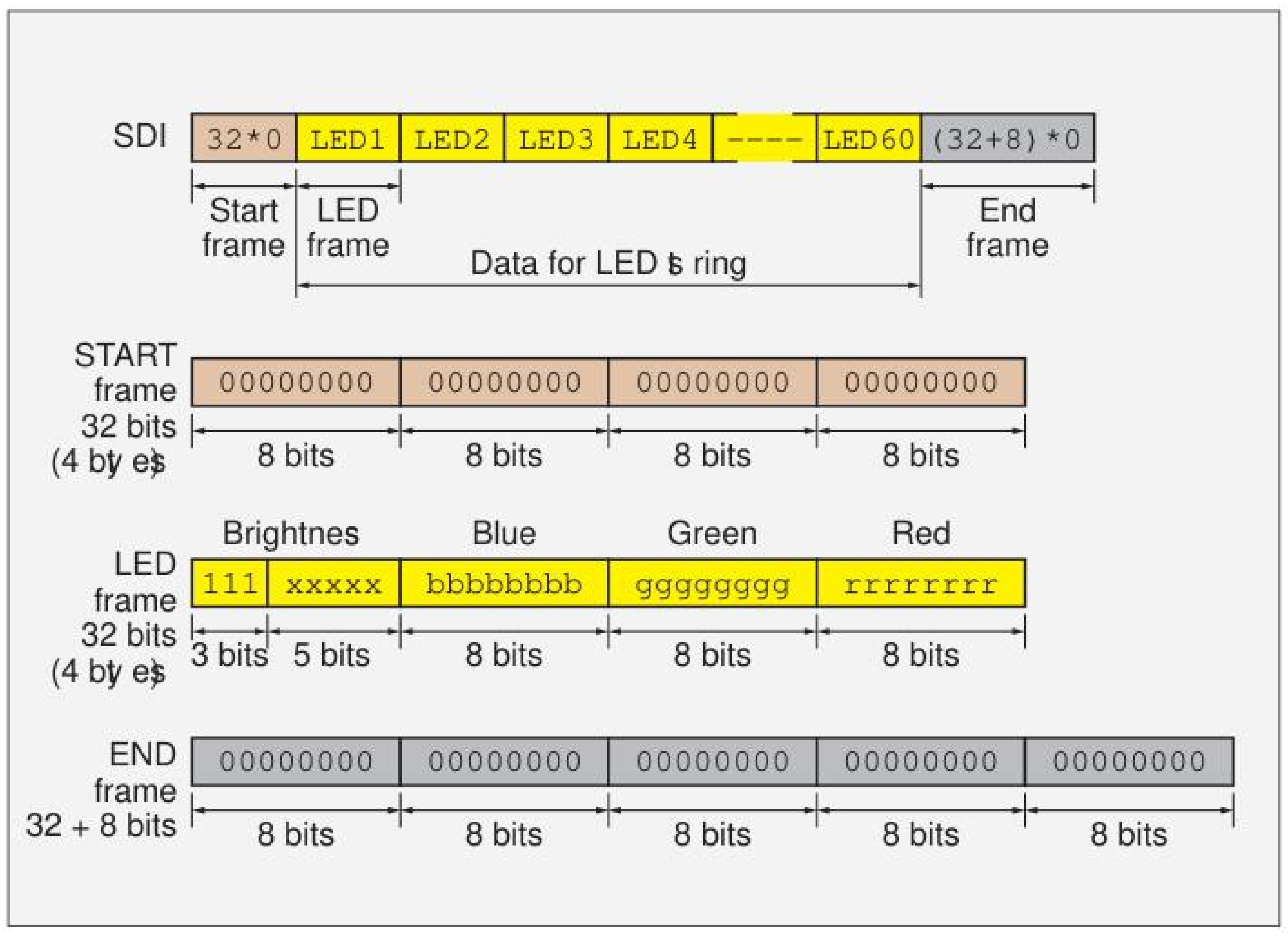


Fig.4. (left) Any shadow LED on the minute and/or hour hand(s) is drawn behind a marker. Here, the time 07:09:28 shows one of the green minute shadow LEDs behind the white 10-minute marker.

Fig.5. (right) The APA102 data communication format. Each RGB LED requires a 4-byte frame to define its brightness and overall colour.



of 4-byte data-frames (one 4-byte frame for each LED). You will also need to send a header and a footer to signify the start and end of the LED frames when communicating with the LED ring.

Fig.5 shows the format of APA102 data communication – the diagram is taken from *Part 13* and has been updated slightly to show the data for the LED string as being 60 frames in length (as opposed to eight frames). Do not worry about the detail for now, it is just for easy reference when viewing the comments in this month's code. The important point to note here is that we have 60 LEDs that can be individually controlled in terms of brightness (one byte in the frame), and colour (three bytes in the frame). It is well worth re-reading *Part 13* to clarify further details.

Defining the seconds hand

Let's now consider how we can position and define the seconds hand. Imagine that in our code we have a way of referring to any of the 60 LEDs by using a reference number between 0 and 59. Imagine also that we can set the colour of the referenced LED as well as its brightness. It would then make sense to use the reference number (between 0 and 59) to represent the position on the clock for the LED we wish to set. To achieve this in code we can simply use four arrays as follows:

`BrBuf()`	stores the brightness value of an LED; between 0 (off) and 31 (full brightness).
`rBuf()`	stores the RED intensity of an LED; between 0 (off) and 255 (full intensity).
`gBuf()`	stores the GREEN intensity of an LED; between 0 (off) and 255 (full intensity).
`bBuf()`	stores the BLUE intensity of an LED; between 0 (off) and 255 (full intensity).

So, to define the seconds hand (red dot) at position 22 (meaning 22 seconds) we just need to set the values in the four arrays as follows:

```
BrBuf(22)=31 ' maximum brightness
rBuf(22)=255 ' full red intensity
gBuf(22)=0   ' zero green intensity
bBuf(22)=0   ' zero blue intensity
```

Note that this does not turn on the relevant LED; the four arrays are simply storing the information that ultimately make up the frame values for the referenced LED. So, the above four lines of code store the required values in the four arrays that will ultimately result in the second hand (bright red dot) being drawn in position 22. When all sixty LEDs have been defined in a similar fashion, we can then call a subroutine that is programmed to send the stored array data to the LED ring via a code loop that uses the SPI command to send all 60 data frames (and the header and footer).

Defining the minutes hand

The minutes hand is similar to the seconds hand, but the relevant minute value between 0 and 59 references a bright *green* LED. If we use the variable `mm` to store the minute value (eg, the 44th minute) then to define the green minute hand we begin with:

```
mm=44         ' define minute position in the array
BrBuf(mm)=31  ' maximum brightness
rBuf(mm)=0    ' zero red intensity
gBuf(mm)=255  ' full green intensity
bBuf(mm)=0    ' zero blue intensity
```

However, as explained above, the minute hand is a dash comprising of five dots, and hence has two adjacent shadow LEDs on each side of the above defined bright green LED. To define the two shadow LEDs *preceding* the bright green minute value, we can use the following:

```
BrBuf(mm-1)=3   ' low value brightness
rBuf(mm-1)=0    ' zero red intensity
gBuf(mm-1)=255  ' full green intensity
bBuf(mm-1)=0    ' zero blue intensity
BrBuf(mm-2)=1   ' minimum value brightness
rBuf(mm-2)=0    ' zero red intensity
gBuf(mm-2)=255  ' full green intensity
bBuf(mm-2)=0    ' zero blue intensity
```

Note that the two shadow LEDs *after* the bright green minute hand would be referenced in a similar manner to the above eight lines of code but with `mm+1`, and `mm+2`. However, there is one thing to note, and it is best explained by using `mm=59`. The two preceding shadow LEDs in this example are not a problem (at array position 57 and 58), but the two shadow LEDs after the minutes hand would be in array positions 60 and 61 – both of these are invalid as we only go up to array position 59. The way we deal with this is easy, since the (invalid) position 60 is the same as (valid) position 0, and position 61 is the same as position 1. To do the calculation for the two shadow LEDs after the central bright green minute 'dot', we will use a variable called `Tmp`, along with an `IF…THEN` statement. We can then adjust array position 60 to 0, and position 61 to 1 as follows:

```
Tmp=mm+1: IF Tmp>59 THEN Tmp=Tmp-60
BrBuf(Tmp)=3    ' low value brightness
rBuf(Tmp)=0     ' zero red intensity
gBuf(Tmp)=255   ' full green intensity
bBuf(Tmp)=0     ' zero blue intensity
Tmp=mm+2: IF Tmp>59 THEN Tmp=Tmp-60
BrBuf(Tmp)=1    ' minimum value brightness
rBuf(Tmp)=0     ' zero red intensity
gBuf(Tmp)=255   ' full green intensity
bBuf(Tmp)=0     ' zero blue intensity
```

In a similar manner, the two shadow LEDs prior to the central bright green minute 'dot' need checking to ensure the calculated array position doesn't equal the invalid values of –1 or –2. Thus:

```
Tmp=mm-1: IF Tmp<0 THEN Tmp=60+Tmp
....                 ‘ low value brightness
Tmp=mm-2: IF Tmp<0 THEN Tmp=60+Tmp
....                 ‘ minimum value brightness
```

The above is not a listing of the complete code, it is purely for explaining the concepts; and will help to make it easier to understand the comments that are in the code.

Positioning the hours hand

Regarding the hours hand (a dash comprising of three blue dots), the first point we need to consider is how to convert the hour value (0 to 23) into a clock position value (0 to 59). Then, as mentioned earlier in the article, the second point to understand is how to make the hours hand slowly progress from one hour marker to the next (while the minutes hand makes its full revolution).

The first point is addressed by taking the hours (`hh`) and using `MOD 12` to obtain a value between 0 and 11. Then multiply it by five to get a clock (array) position. So, if we are in the 14th hour (`hh=14`) the resulting hours clock position is `(14 MOD 12)* 5 = 10`.

The second point is addressed by then adding a value between 0 and 4 to the hours clock position we calculated above. It may seem complicated, but do stick with me. The exact value (0-4) needed to be added to the hours clock position is determined by the minutes value (just as it is on an analogue clock). Having five available progressive step positions for the hours hand means that we can divide an hour (60 minutes) into five equal 'windows' of 12 minutes each. So, assuming the minutes value is stored in variable `mm`, when `mm` is between 0 and 11, we add 0 to the hours clock position, and when `mm` is between 12-23 we add 1, and so on (24-35 add 2, 36-47 add 3, and 48-59 add 4). There is a useful operator in MMBASIC that we can use to return the integer part of a division – this is the '\' operator as opposed to the usual '/' divide operator (which returns the complete value of a division, not just the integer part). Used correctly with `mm`, the '\' operator returns the relevant value between 0 and 4 to be added to the hours clock position value.

All of the above determines the position of the central dot in the hours dash (which in total comprises this central bright blue dot, along with two adjacent shadow LEDs). We then need to use similar checking to ensure that we don't end up with an invalid array position such as –1 or 60 (no other invalid values are possible for the hours hand if you follow the logic through). So, our code to define the blue hours hand becomes:

```
‘ convert hours (0-23) into clock position (0-59)
hh=((hh MOD 12)*5)+(mm\12) ‘and add step-increment
BrBuf(hh)=22           ‘set brightness
rBuf(hh)=0             ‘RED intensity
gBuf(hh)=0             ‘GREEN intensity
bBuf(hh)=255           ‘BLUE intensity

Tmp=hh-1:If Tmp<0 Then Tmp=60+Tmp
BrBuf(Tmp)=3           ‘shadow brightness
rBuf(Tmp)=0            ‘RED intensity
gBuf(Tmp)=0            ‘GREEN intensity
bBuf(Tmp)=255          ‘BLUE intensity

Tmp=hh+1:If Tmp>59 Then Tmp=Tmp-60
BrBuf(Tmp)=3           ‘shadow brightness
rBuf(Tmp)=0            ‘RED intensity
gBuf(Tmp)=0            ‘GREEN intensity
bBuf(Tmp)=255          ‘BLUE intensity
```

This concludes the explanation of how the clock's three hands are defined in terms of values stored in the four arrays. We will now quickly discuss how we define the 12 white 'hour' markers.

Defining the markers

This is really simple – I promise! All we need to do is set the LEDs at positions 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, and 55 to a low intensity white colour, and then the LED at position 0 to a slightly brighter white. We can do this with a `FOR…NEXT` loop as follows:

```
FOR count=5 TO 55 STEP 5
   BrBuf(count)=1  ‘set minimal brightness
   rBuf(count)=3   ‘RED intensity
   gBuf(count)=3   ‘GREEN intensity
   bBuf(count)=3   ‘BLUE intensity
NEXT count
‘ now define the brighter marker at position 0
BrBuf(0)=16
rBuf(0)=3
gBuf(0)=3
bBuf(0)=3
```

Overall program flow

Now that we have covered the building blocks for our GPS analogue clock, we will next discuss the sequence of steps that our program code follows in order for it to perform as we desire. This will be kept to a high level as there are the usual supporting comments in the program code that explain things further.

1. On power-up, the `TIME$` system variable starts at `00:00:00`
2. The `Brightness` value is set to the maximum value (31)
3. The *MKC* checks for a valid GPS signal. If valid, the `TIME$` is set to the amended UTC value (as described last month)
4. The current `TIME$` is displayed on the LED ring as follows:
   - **a)** `SUB ClearBuffer` ensures that all 60 array elements are cleared to the following values:
     ```
     BrBuf()=Brightness
     rBuf()=0
     gBuf()=0
     bBuf()=0
     ```
   - **b)** The hours, minutes and seconds values are extracted from the `TIME$` variable, and loaded into variables `hh`, `mm` and `ss`
   - **c)** `SUB DrawMinutes` is called and sets the relevant array values to define the green minutes hand (as described above)
   - **d)** `SUB DrawHours` is called and sets the relevant array values to define the blue hours hand (as described above)
   - **e)** `SUB DrawMarkers` is called to define the twelve white markers (as described above)
   - **f)** `SUB DrawSeconds` is called to define the red seconds hand (as described above)
   - **g)** `SUB SendLED` is called to output the array data in an SPI format (as outlined in Fig.5)
5. Program returns back to repeat from Step 3

The program code for the analogue clock (**GPS_AnalogueClock.txt**) can be downloaded from November 2020 page of the *PE* website. Do read through the comments in the code, along with the above notes, and the ideas will fall into place. Now that we have covered the design, theory, and have the code loaded, it is just a matter of connecting up the necessary hardware.

Circuit diagram

Please refer to Fig.6 for the schematic of the *MKC GPS Analogue Clock*. As can be seen, there are only three hardware elements to the complete design: the *MKC*, the GPS module, and the LED ring. The GPS module requires 5V power, and a single UART data link between the GPS Tx pin, and the Micromite's COM1 Rx pin (pin 22) – this is as described last month.

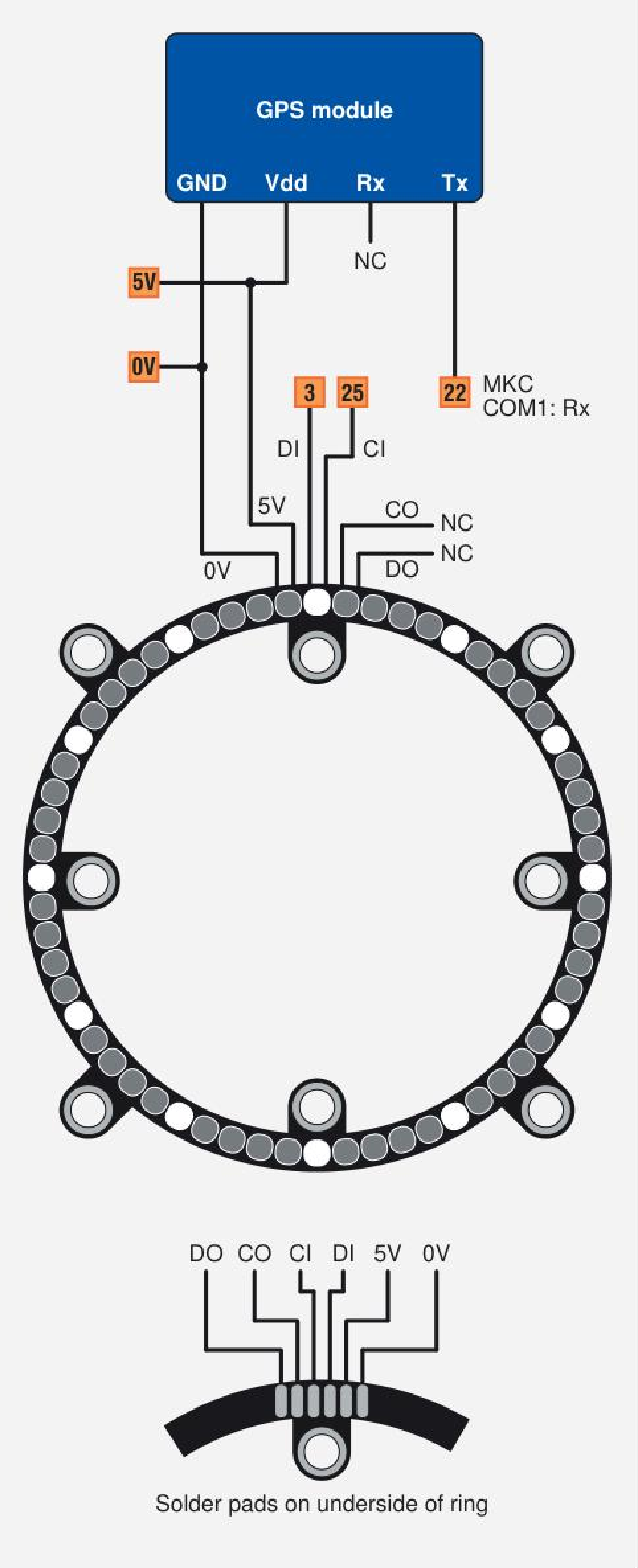


Fig.6. The schematic of the *MKC GPS Analogue Clock*. There are just seven connections to be made between the *MKC*, GPS module, and the LED ring, as shown here.

The LED ring also requires 5V power and is connected to the Micromite's SPI Dout pin (pin 3) and the Micromite's SPI Clock pin (pin 25) – this was effectively described in *Part 13*.

Assembly

The only constructional challenge is attaching the four inter-connecting cables to the LED ring. We used a spare female-to-female connector ribbon cable since these contain stranded cable inside each conducting wire (making it more flexible than if it were solid core cable). We tore off four cables to meet our requirements and then cut off the four connectors from one end. Next we removed four short pieces of insulation from the cut end, and tinned them in preparation for soldering them to the four relevant pads on the back of the RGB ring. The end result is a short 4-way ribbon cable soldered at the LED ring end, and four female connectors at the other end into which we can insert male-to-male jumpers to connect it to the *MKC* – see Fig.7. Be sure to connect 5V power (from the *MKC*) to the correct two points on the LED ring, otherwise it may be damaged.

With the GPS module and the LED ring connected to the *MKC* (and with the Analogue Clock program code loaded), power up your *MKC*, type `RUN` and you should see the LED ring come to life. If not, then recheck all four power connections that supply 5V power to the two modules, and also check the correct SPI pins (pin 3 and 25) are connected to the correct two pads on the LED ring.

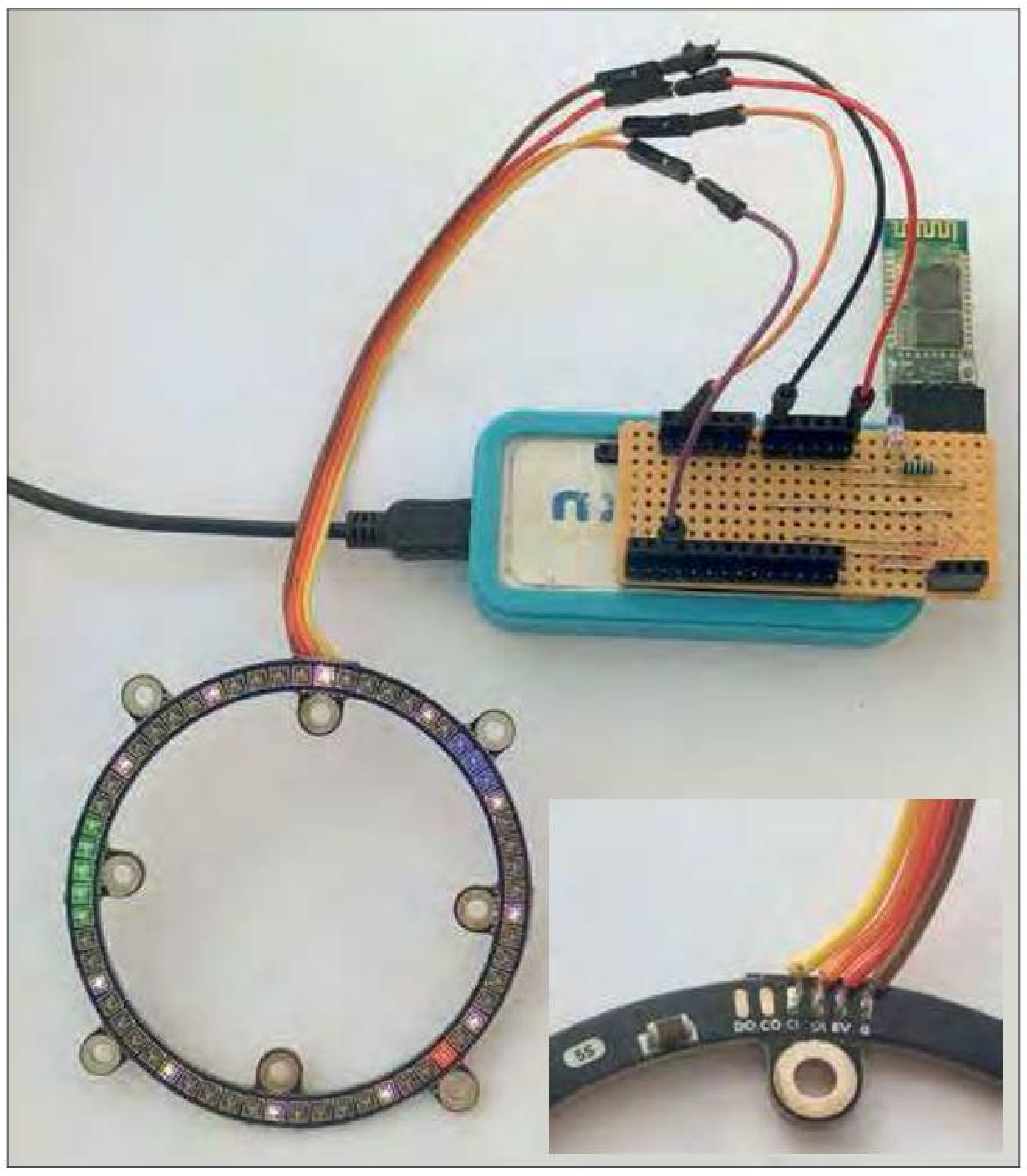


Fig.7. Four connecting cables are made from cutting down a female-to-female ribbon cable (see inset lower right). Normal male-to-male jumper wires are then used to connect the LED ring to the *MKC*, as shown here.

Initially the LED ring will not display the correct time because the Micromite always resets the time to 00:00:00 on power-up. Only when a valid GPS signal is received will the time be displayed correctly. If the correct time is not displayed within three minutes, then it will be worth repositioning your GPS module (or externally mounted antenna) to a location that has a better view of the sky (in order to pick up clear satellite signals). Do remember to set the correct UTC offset at the start of the program. The offset value depends on which time zone you are in, as well as any daylight saving – see the comments contained in the code.

That concludes the build of the *MKC GPS Analogue Clock* – once again, this project has shown you just how easy it is to use minimal hardware and just a few lines of BASIC code to create a useful product that can then be customised by simply making a few changes to the code.

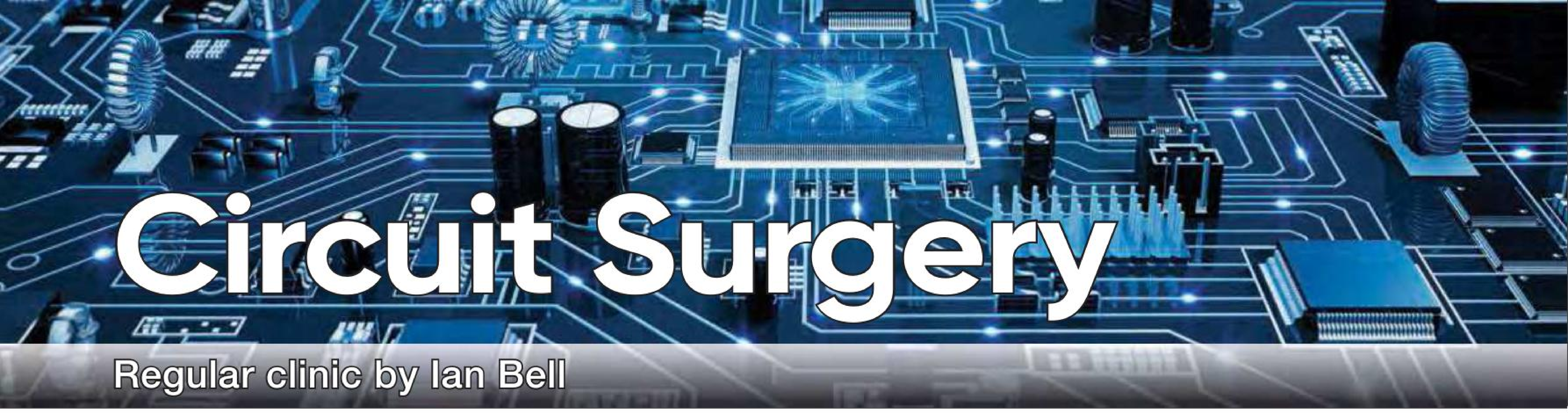
Challenges

There are endless modifications you could make to the code this month. We would always encourage you to change the code as it is a fantastic way to learn, and it also ensures that you understand the concepts presented. To give you some ideas as to what you could try, have a go at coding some of the following:

1. Change the colours and brightness of the hands and markers to suit your own personal preference.
2. Have an indication as to when a valid GPS signal is being received – for example, use the 12:00 marker (the upper most marker) and use one colour such as white to indicate a valid GPS signal, and another colour such as yellow to indicate no GPS signal.
3. Add an RTC module from the IPS Display Module (IDM) and use the GPS signal to periodically update the time stored in it, ensuring it is always accurate with zero drift.
4. Add an LDR (light-dependent resistor) to an analogue input pin to sense the light level in the room. Then have the code automatically adjust the brightness of the LEDs. This allows you to dim the display in a darkened room (eg, at night) so that the LEDs aren't too bright. Likewise, in a well-lit room, the LEDs can be made brighter so that the clock is more visible.
5. Add an IR receiver and a piezo sounder to make an alarm clock. Use a remote control to switch between the actual time, and the alarm time (use colour to indicate what is currently being shown). Use cursor keys on the IR remote to select between setting the alarm hours and minutes. Use the remote to silence (or snooze) the alarm. Use `VAR SAVE` and `VAR RESTORE` to save (and recall) the alarm time.
6. Use a different method to display the time in the analogue format – making it easy for anyone to read the time.

I hope these have provoked some ideas – and please do email us with anything that you create, and that you feel is worth sharing. Until next month, have *fun* coding!

Questions? Please email Phil at:
contactus@micromite.org



Circuit Surgery

Regular clinic by Ian Bell

Analogue multipliers

This month's Circuit Surgery topic was suggested by *PE* editor Matt Pulzer and is analogue multiplication. This was partly inspired by Julian Edgar's exercise bike project (see page 41), where measurement of output power would be a useful feature. Power is the product of current and voltage, so multiplication of a voltage and current measurements can provide a power reading. Power measurement is just one possible use of a multiplier circuit, and this article will be looking at this topic in general, not just this application.

Multiplication is a mathematical operation and these days we commonly think of mathematical processing of signals as most easily performed by digital processing – signals are converted using digital-to-analogue converters and calculations are performed by microcontrollers or larger processors, depending on the application. However, mathematical operations such as multiplication, logarithms and integration can also be performed by analogue circuits.

The well-known op amp (operational amplifier) gets its name because it formed the basis of analogue computers which predated digital computers. Op amp circuits can be configured to perform a variety of basic mathematical *operations* that can be wired together to form larger circuits which solve complex mathematical problems. Analogue computers were used in applications such as the simulation of dynamic systems (eg, aircraft) before the days of digital computer-aided design. Although op amps are often the basis of analogue circuits that perform mathematical operations, including multiplication, multiplication is a function which can also be implemented using special transistor-level circuits.

In most contexts, analogue computers have been supplanted by digital ones with which we are all familiar; however, digital processing of analogue signals is not always the best approach. For example, for high-frequency signals (tens to hundreds of megahertz and above), digital processing requires high-speed DACs and fast digital processing, which can be performed with similar or better performance at lower cost using analogue circuits. If the result is only needed in analogue form, then this eliminates the need for digital processing. In situations such as closed-loop control, direct analogue multiplication can provide the fast response required. If the result is needed digitally (for example to log or display information for users) then a lower-cost data conversion and processing can be used (perhaps a cheap microcontroller).

Symbols, scaling and quadrants

An analogue multiplier is a circuit which takes two input voltages V_X and V_Y, and produces an output which is proportional to their product ($V_X \times V_Y$). Usually there is a scaling factor involved, so we write the output as $K(V_X \times V_Y)$ or $(V_X \times V_Y)/K$, where K is a constant value. Consider a multiplier circuit working on a 10V supply, with maximum signal values also of 10V. In this scenario, two inputs of 10V and a function of ($V_X \times V_Y$) would imply an output of 100V, which is well beyond the supply and probably impractical. If the multiplied value is divided by 10, so the function is $0.1(V_X \times V_Y)$ or $(V_X \times V_Y)/10$ then the output range is well matched to the input range.

Multipliers can be represented as circuit blocks in schematics and typically have a symbol based on a box or circle with an '×' inside it (see Fig.1).

Last month, we discussed single-supply op amp circuits – they are convenient in terms of power supply simplicity but are not able to handle input signals of both polarities. The issue of signal polarity is important for multiplier circuits, where we have two input signals, and therefore four possible combinations of input polarities: ++, +−, −+ and −−; these are referred to as four quadrants. If you plotted the two input signals against one another on a graph the pairs of polarities would correspond to the four quarters of the graph, as divided by the axes.

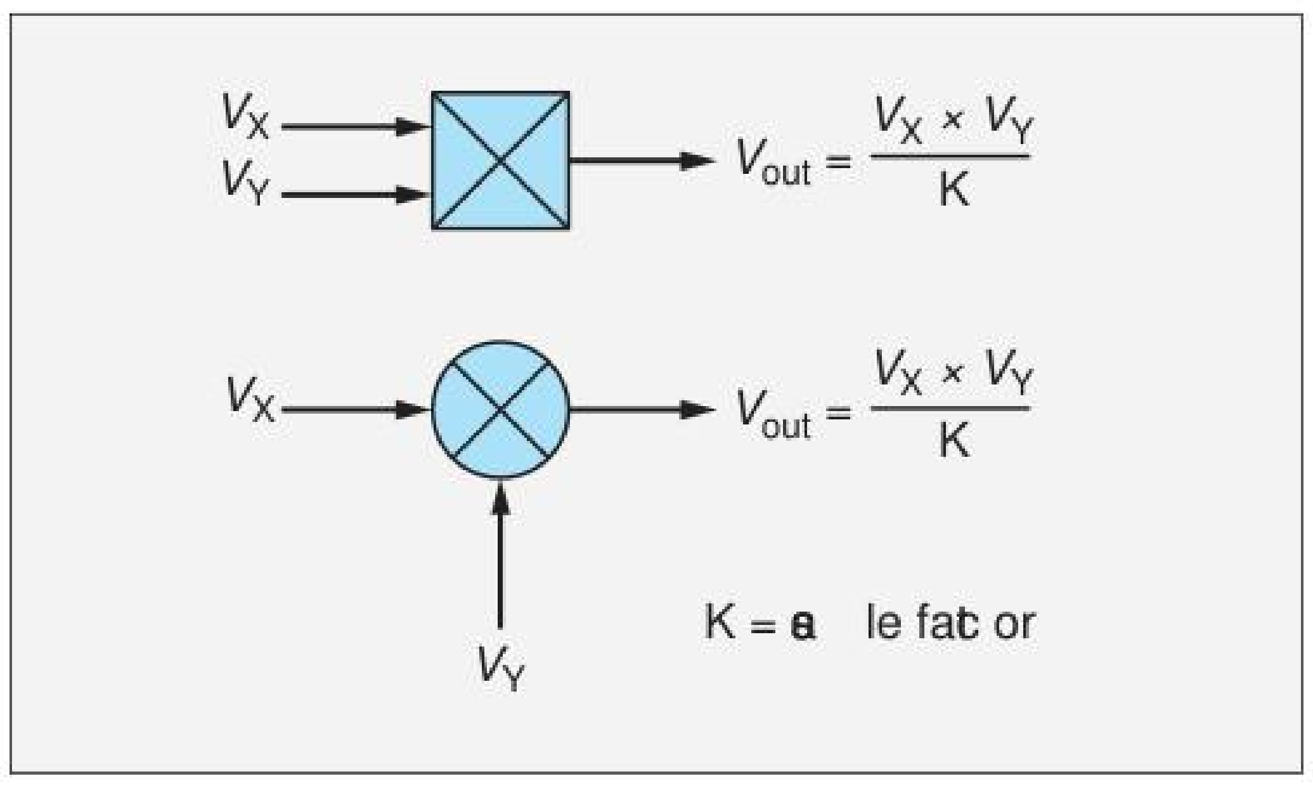

V_X
V_Y
$V_{out} = \frac{V_X \times V_Y}{K}$
V_X
$V_{out} = \frac{V_X \times V_Y}{K}$
V_Y
K = a le fat or

Fig.1. Multiplier circuit symbols

For multiplier circuits we are interested in whether or not a bipolar input signal (one that can be both positive and negative) can be handled or not on each input. This leads to three cases. If both inputs are unipolar, then the circuit only operates in one of the four quadrants and the output will have fixed polarity (which could be either positive or negative). If just one of the signals can be bipolar, then the circuit operates in two of the four quadrants, and the output is bipolar (changing the sign of one term in a multiplication, but not the other, changes the sign of the result). Finally, if both inputs can be bipolar, then the circuit covers all four quadrants and has a bipolar output. Thus, multiplier circuits are classed as one, two or four-quadrant multipliers. Although four quadrants may appear to be the best option, it is not needed in all applications and circuitry may be simpler for fewer quadrants.

Mixers and modulators

A key application of multiplier circuits is mixers in radio circuits. The term 'mixer' is potentially confusing – a typical audio-frequency mixer (as in the circuitry of an analogue mixing desk) *adds* multiple signals, whereas a typical radio-frequency mixer *multiplies* two signals. The purpose of multiplicative, or frequency mixing, is to create new frequencies – typically the sum and difference of the two input frequencies. Such circuits may also be also referred to as 'modulators' or 'demodulators', depending on the application.

The shifting of one frequency range to another frequency is sometimes called 'heterodyning', particularly in the context of radio circuits such as superheterodyne radio receivers, where received signals are shifted to a lower intermediate frequency to make further signal processing easier. Although often associated with radio, multiplicative mixing for frequency shifting can also be used at low frequencies, for example in chopper-stabilised amplifiers for low-noise amplification of low-frequency signals. Another use of multiplicative mixing is in lock-in amplifiers. These instruments can be used to measure very small signals (or more accurately, signals with very high noise levels) at specific frequencies (a single target frequency, so it is a homodyne, rather than a heterodyne circuit).

Multiplicative mixing can be achieved without using an obvious multiplier circuit – we can simply apply the sum of two signals to a nonlinear element, typically a diode. A portion of current in the diode will be proportional to the product of the two signals. The diode's exponential voltage-to-current relationship can be *approximated* by an expression including the square of the voltage – and squaring the sum of two values produces the product, among other terms. The portions of the current other than the product are small enough to be ignored, or can be filtered out as they are at different frequencies. However, the *ideal* frequency-shifting mixer is a perfect multiplier circuit.

Consider two sinusoidal signals of frequencies f_1 and f_2, which can be represented as a function of time by $A\cos(2\pi f_1 t)$ and $B\cos(2\pi f_2 t)$, where A and B are the signal amplitudes. The 2π factor converts the ordinary frequency of the signal (f) in hertz to an angular frequency in radians. Multiplying the two signals gives:

$$A\cos(2\pi f_1 t)\,B\cos(2\pi f_2 t)$$

To see the implications of this clearly in terms of frequencies we need to convert the product of two cosines to separate sine or cosine functions. We can use the prosthaphaeresis formulas – a set of four trigonometric identities, of which we need:

$$\cos\alpha\cos\beta = \frac{1}{2}\cos(\alpha-\beta) + \frac{1}{2}\cos(\alpha+\beta)$$

Applying this to the multiplied signal expression gives:

$$\frac{AB}{2}\cos(2\pi(f_1 - f_2)t) + \frac{AB}{2}\cos(2\pi(f_1 + f_2)t)$$

This shows multiplied signal consists of the sum ($f_1 + f_2$) and difference ($f_1 - f_2$) frequencies. Using the same trigonometric identities and a little algebra, it can be shown that if one input is equal to $1+A\cos(2\pi f_1 t)$, then the output also includes that original frequency.

Power measurement

Frequency-shifting mixing circuits are not the only application of multipliers. In some cases, we simply want to perform a multiplication operation on two signal values and use the resulting value directly. As indicated earlier, an example of this is in measurement of power. In cases where the voltage (V) is well regulated and can be assumed to be fixed, power can be obtained simply by measuring current (I) and scaling appropriately, but if the voltage can then vary this approach will not provide accurate power measurement and it will be necessary to calculate $I \times V$, or IV for short. Power (P) is the product of voltage and current ($P = IV$), so if we have two voltages, one proportional to the voltage applied to a load (V_V) and the other proportional to the current through it (V_I), then multiplying these voltages with an analogue voltage multiplier will produce a signal (V_P) which is proportional to the instantaneous power in the load. Note that we do not necessarily use the load voltage directly as it may not be in a range suitable for the multiplier. Fig.2 shows how this might be achieved – the current is sensed by a small resistor (R_{SENSE}) in the supply line – the voltage drop across this is V_I, which is applied to a multiplier. A potential divider provides a proportion of the supplied voltage (V_V) to the other input of the multiplier. The differential multiplier output is converted to single-ended signal and scaled by a constant (K_p) by the amplifier. This circuit is similar to part of the LT2940 power monitor IC from Analogue Devices.

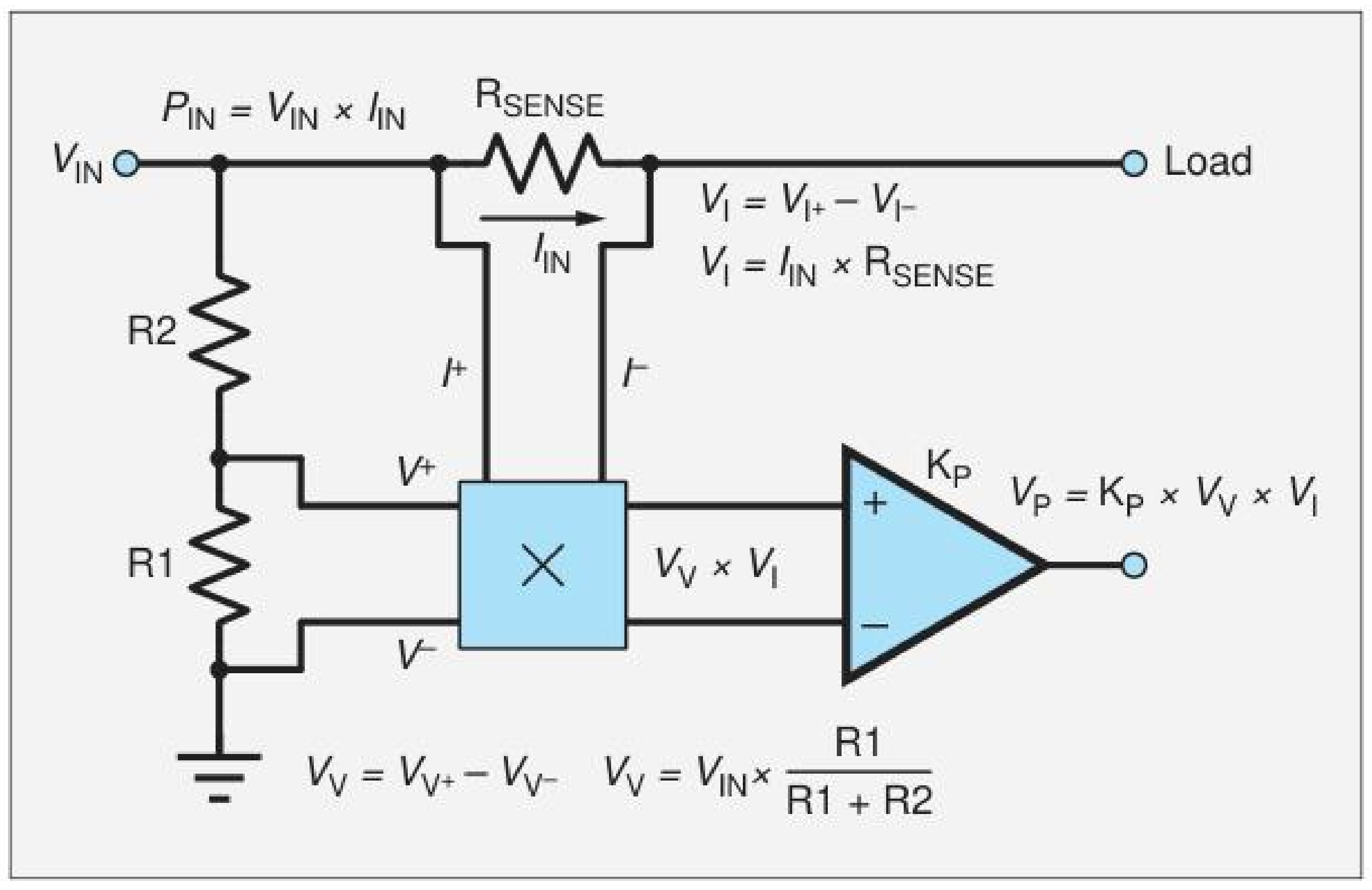

$P_{IN} = V_{IN} \times I_{IN}$
R_{SENSE}
V_{IN}
Load
$V_I = V_{I+} - V_{I-}$
I_{IN}
$V_I = I_{IN} \times R_{SENSE}$
R2
I^+
I^-
V^+
K_P
$V_P = K_P \times V_V \times V_I$
R1
$V_V \times V_I$
V^-
$V_V = V_{V+} - V_{V-}$
$V_V = V_{IN} \times \frac{R1}{R1 + R2}$

Fig.2. Power measurement circuit concept

Quarter-square multipliers

There are a number of ways of implementing analogue multipliers. An approach used in old analogue computers (for example, in the 1960s) was to use quarter-square multipliers. The quarter-square function is just what is says on the tin – the square of a value divided by four. For example, the quarter square of x is $x^2/4$. If you have two values, x and y, you can multiply them using the quarter square of their sum and difference:

$$xy = \left[\frac{(x+y)^2}{4}\right] - \left[\frac{(x-y)^2}{4}\right]$$

Try it with $x = 4$ and $y = 5$. Quarter square tables were used by people in a similar way to tables of logarithms; tables of quarter squares were published from early in the nineteenth century, but the technique may date back to ancient Assyro-Babylonian mathematics. A key feature of using quarter-square tables for multiplication is the table values can be provided as whole numbers because the fractional parts cancel when the difference between the sum and difference quarter squares is taken.

Implementing the quarter-square multiplication using op amp circuits requires the straightforward sum, difference and scaling operations. Squaring is trickier but can be achieved using piecewise approximation. The basis of a circuit which can achieve this is shown in Fig.3 – this is called a piecewise function generator or diode function generator.

To simplify the explanation, we will assume an idealised diode that conducts in one direction and not the other, ignoring the forward-voltage drop and assuming very low resistance when the diode is conducting. Consider just the R_{I1}, R_{B1} and D1 network in Fig.3, along with the op amp. For zero input voltage, the potential divider formed by R_{I1} and R_{B1}, together with the reference voltage ($-V_{ref}$) set a bias voltage at V_{B1} of $-V_{ref}R_{I1}/(R_{I1} + R_{B1})$; call this voltage $-V_{break1}$. If we make the assumption that V_{ref} is a very large voltage compared to V_{IN} and $V_{break}1$, so that R_{B1} is much larger than R_{I1}, then the current in the potential divider will not change much with varying V_{IN}. This means that V_{B1} will track V_{IN}, starting at $-V_{break1}$ for $V_{IN} = 0$ and increasing by an amount equal to V_{IN} as V_{IN} becomes more positive.

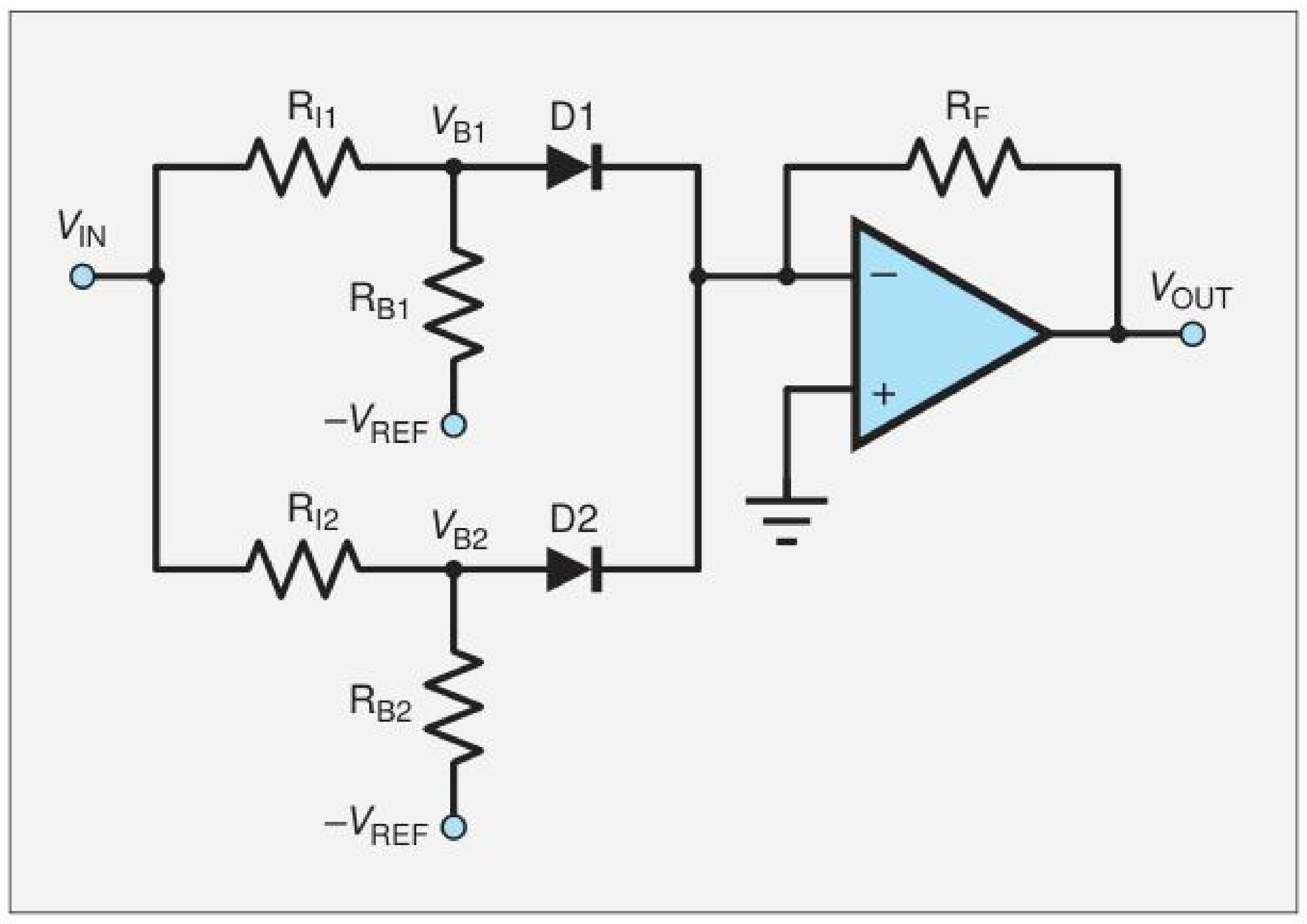


Fig.3. Diode function generator example

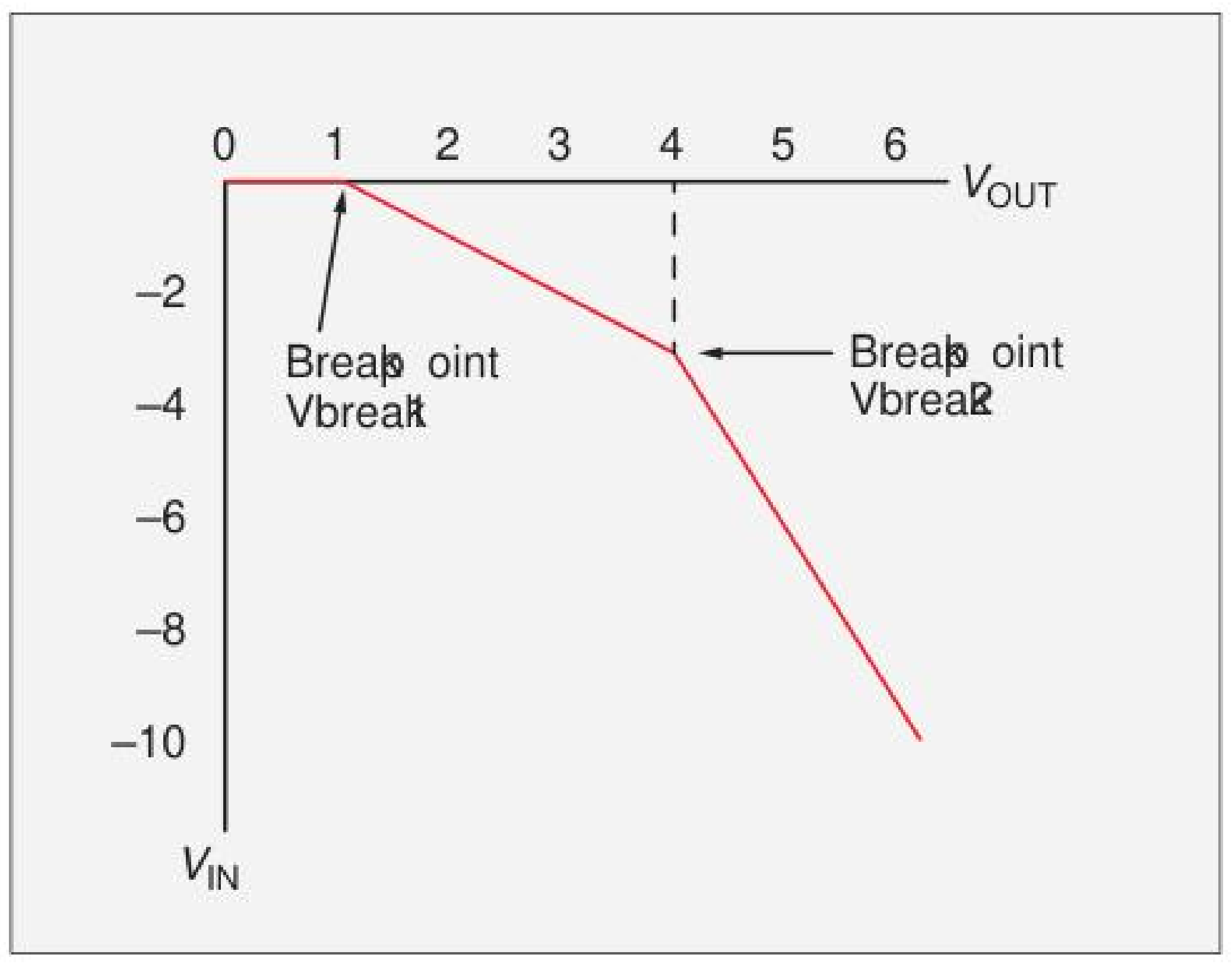


Fig.4. Diode function generator example of input-output relationship.

When V_{IN} is at or below $+V_{break1}$ then D1 is reverse-biased (not conducting) and the input is disconnected from the op amp. The op amp output will be zero. Once V_{IN} rises above $+V_{break1}$ the voltage across the diode will rise above zero and it will conduct. This connects the input to the op amp via R_{IN1}, so we have an inverting amplifier with gain R_F/R_{IN1}. Thus for V_{IN} below $+V_{break1}$ the output is zero, and above this it is $-(R_F/R_{IN1})V_{IN}$. V_{break} is so named because it represents a breakpoint in the input-output characteristic of the circuit.

Now consider the second input network, R_{I2}, R_{B2} and D2. This works in the same way as the first. If we set $+V_{break2}$ to a value larger than $+V_{break1}$ then the circuit will operate as described above until V_{IN} reaches $+V_{break2}$. At this point D2 will also connect, so V_{IN} will be connected to the op amp by both R_{I1} and R_{I2}. Now the inverting amplifier has an effective input resistance equal to the parallel combination of R_{I1} and R_{I2}, so the gain of the circuit will increase – there is a second breakpoint in the characteristic.

Fig.4 shows an example plot of V_{OUT} against V_{IN}. $+V_{break1}$ is 1V, below this the gain is zero and the output is constant at 0V. Above $+V_{break1}$ the gain is 1; a 3V input change from 1V to 4V results in a 3V output change from 0 to –3V. The second breakpoint is at 4V, where the gain increases to 3.5; a 2V input change from 4V to 6V results in a 7V output change from –3V to –10V.

The circuit in Fig.3 forms the basis of creating a customised input-output relationship which can be fitted to a mathematical function such as squaring by suitable choice of breakpoints and gains. More input networks can be added to more accurately shape the function.

The circuit in Fig.3 has a single input, but more than one input can be connected to each diode via separate resistors, as shown in Fig.5 (this shows just one diode network, but more can be added). This creates a circuit similar to a standard op amp summing amplifier, but with the piecewise linear function shaping the response, as just discussed. For example, if the function curve was set to follow a square law, then two inputs (say V_X and V_Y) on equal resistors would give an output proportional to $(V_X + V_Y)^2$. If V_Y was passed through a unity-gain inverting amplifier before being applied to this circuit (to obtain $-V_Y$) the output would be $(V_X - V_Y)^2$. These are the two functions required to implement a quarter-square multiplier.

Log/antilog multipliers

As mentioned above, tables of logarithms were commonly used to help perform calculations until the pocket calculator became widely available. To multiply x and y with logarithms we find the sum of the log of x and the log of y, and then take the antilog of the result:

$$xy = \text{antilog}[\log(x) + \log(y)]$$

In circuit terms, this translates to the block schematic shown in Fig.6. The summing amplifier is a well-known op amp circuit. It is also possible to build log and antilog circuits using op amps.

The most basic forms of log and antilog amplifiers are shown in Fig.7 and Fig.8. These circuits use the exponential (exp) relationship between the applied voltage and current in a diode.. The exponential function ($\exp(x) = e^x$) is the antilog of the natural (base e) logarithm (ln). It follows that the voltage drop across a diode is proportional to the natural logarithm of the current through it.

For the log amplifier (Fig.6) the input voltage causes a current to flow in the resistor R1. Assuming an ideal op amp, the inverting input behaves like ground in this circuit, so the current is V_{IN}/R1. For an ideal op amp, which has zero bias current and infinite input impedance, all of this current flows into the diode. The output voltage is equal to the diode voltage, which is proportional to the natural log of the current in the diode, which is in turn proportional to the input voltage – so the output voltage is proportional to the natural logarithm of the input voltage.

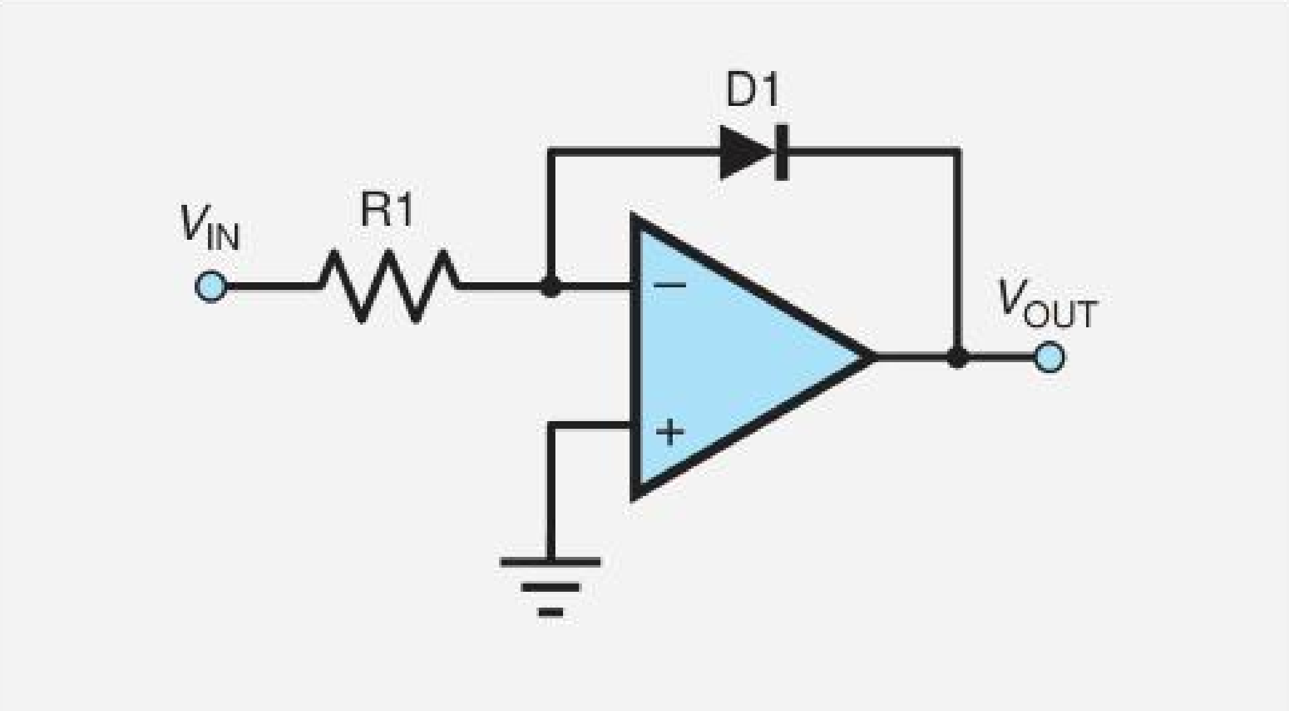


Fig.7. Diode logarithmic amplifier.

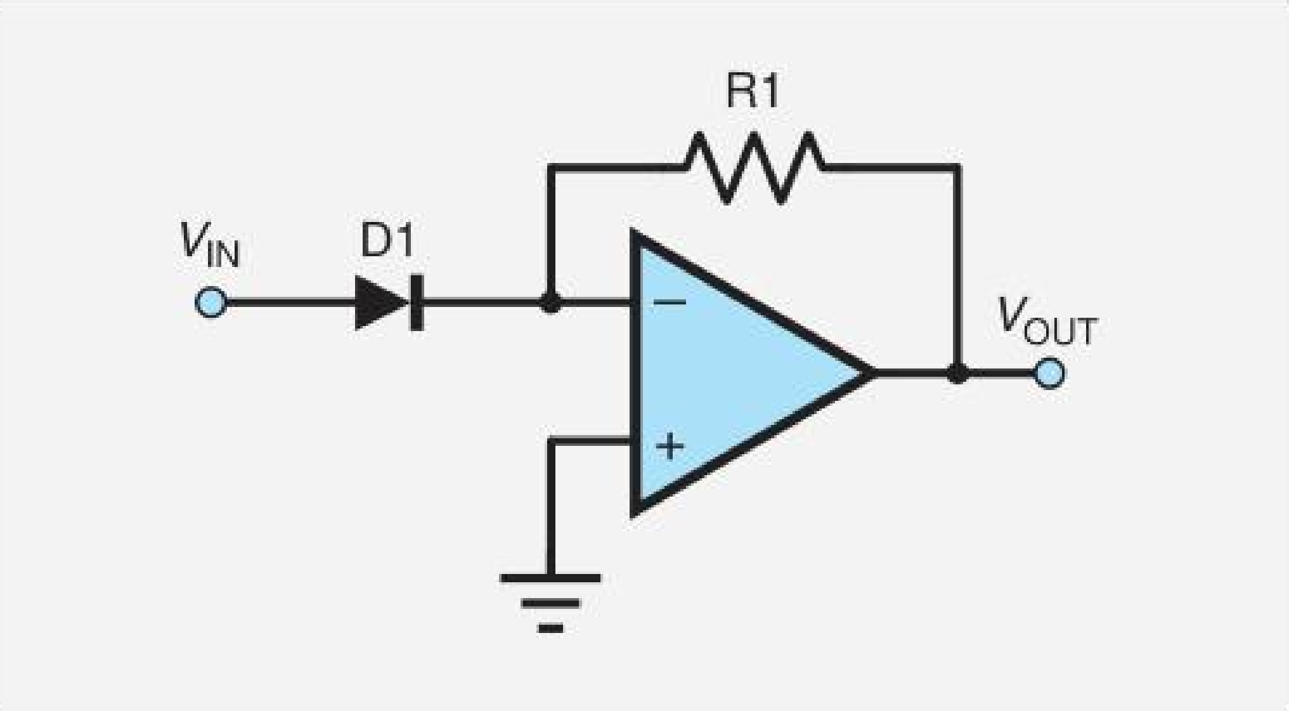


Fig.8. Diode exponential/antilog amplifier.

For the exponential/antilog amplifier a similar argument shows that the diode current is proportional to the exponential of the input voltage. All of this current flows in the resistor (R1), so the voltage drop across the resistor is proportional to the exponential of the input voltage and the voltage drop across R1 is equal to the output voltage.

Log and antilog amplifiers often use transistors instead of diodes and may be much more sophisticated than the circuits shown here. They are interesting and useful circuits and we hope to look at them in more detail in a future article. However, as far as multipliers are concerned, they are not the best option.

Transistor multiplier circuits

Although the op amp circuits described above can implement multiplication the best approach is to use circuits which implement the multiplication more directly with a few transistors. A widely used circuit is called a 'Gilbert cell' multiplier after it's inventor Barrie Gilbert, who published it in 1967. In fact, a variety of circuits can be based on the same principle which Gilbert termed 'translinear' circuits because they are based on the linear dependence

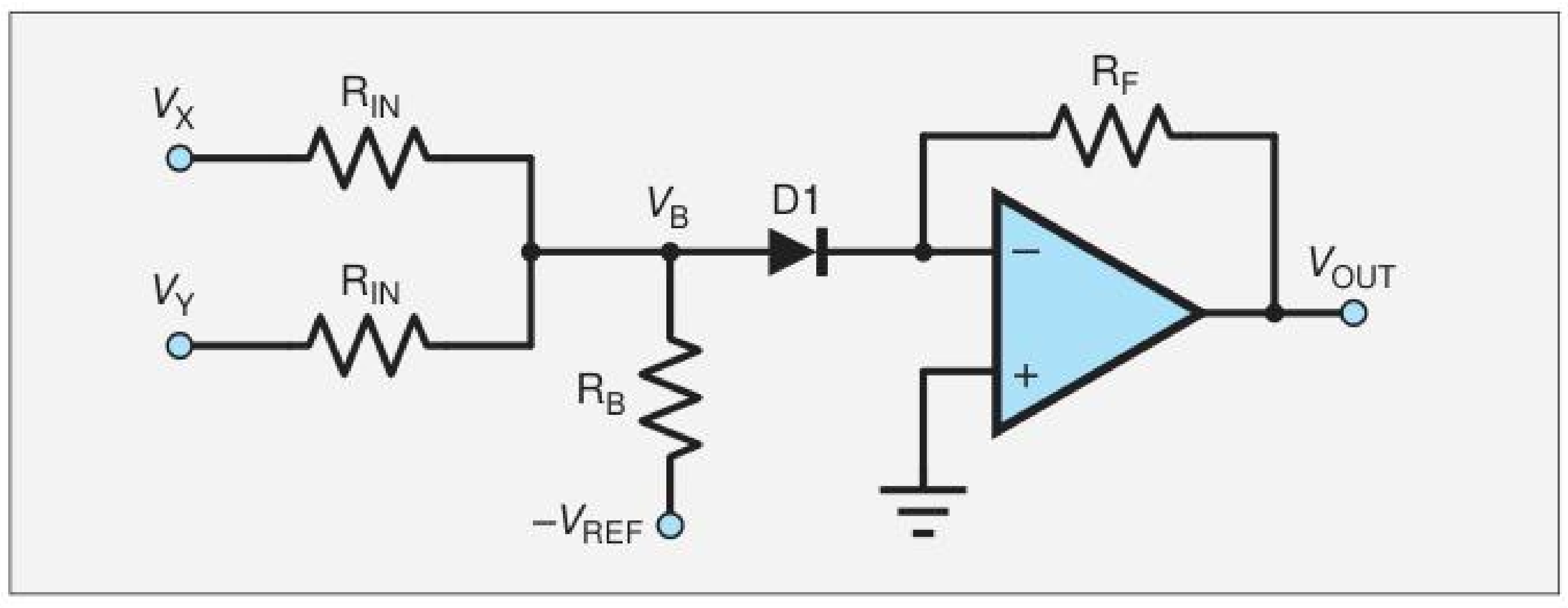


Fig.5. Diode function generator with summed inputs.

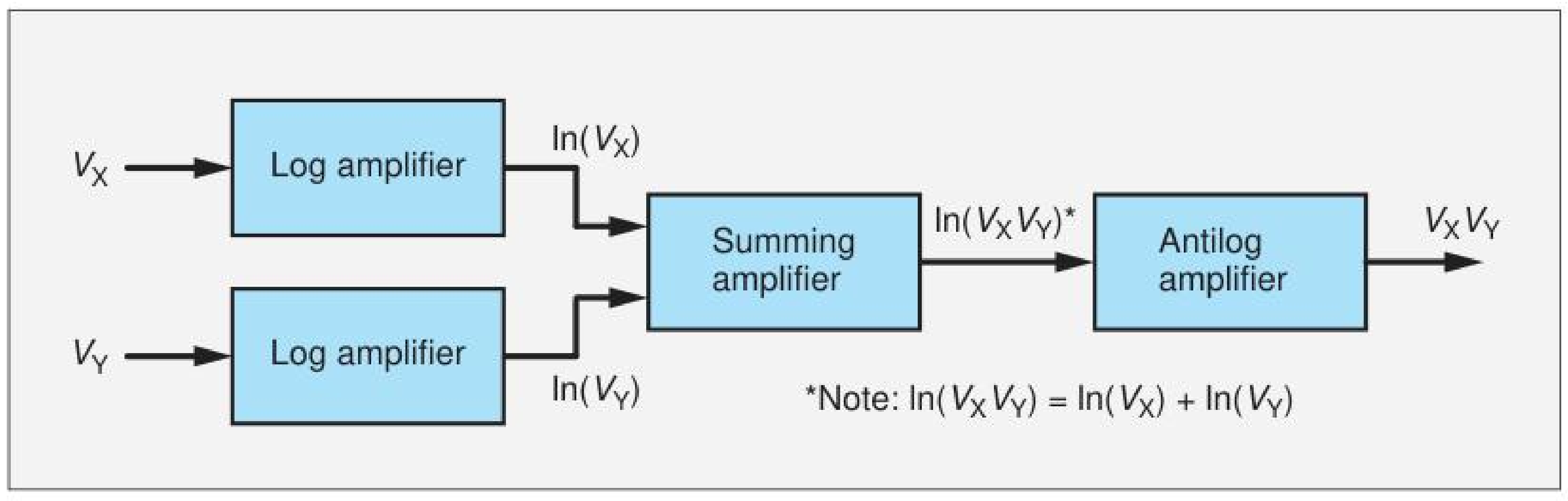


Fig.6. Block diagram of multiplier based on log and antilog amplifiers.

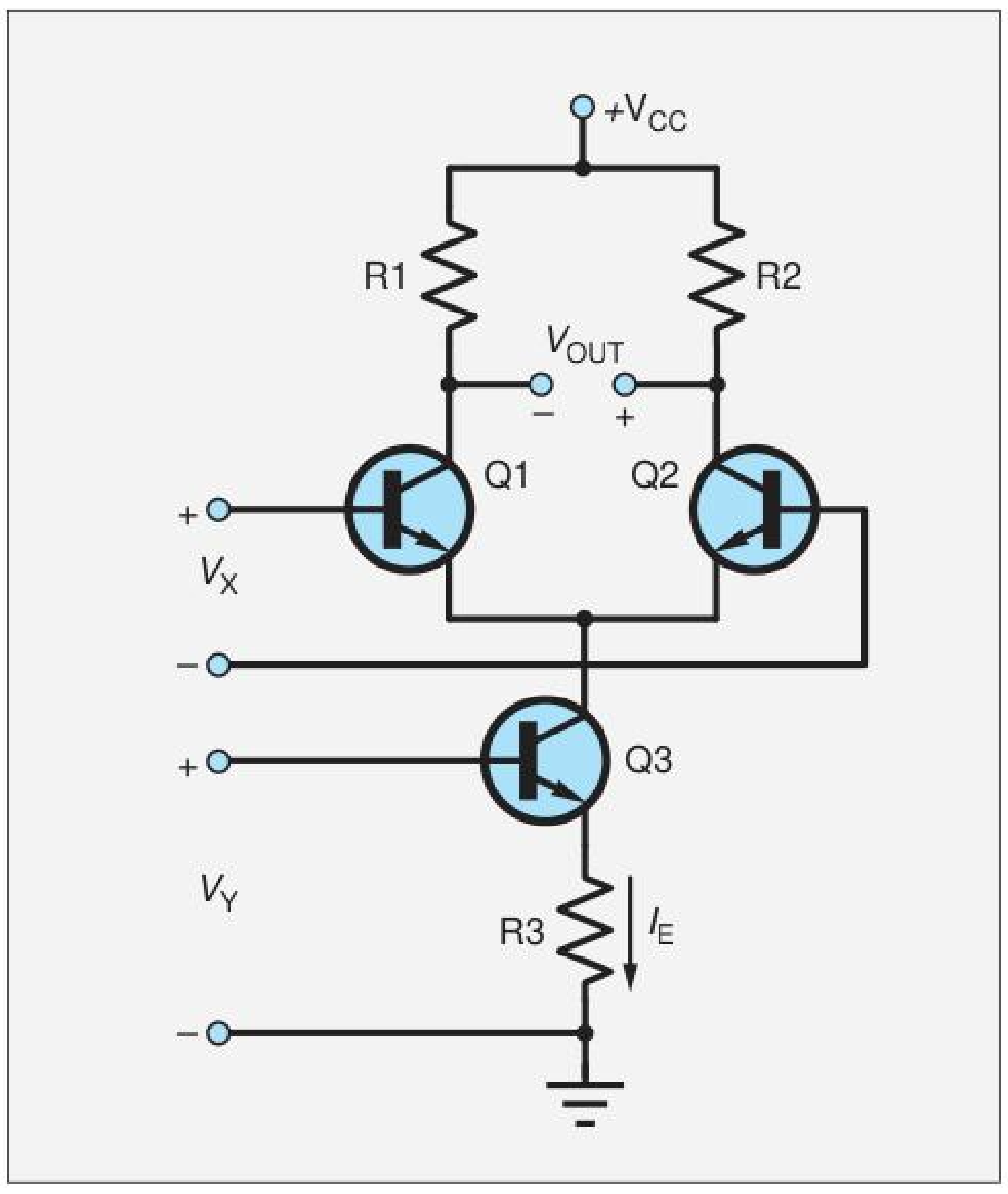


Fig.9. Multiplier based on a variable transconductance differential amplifier.

of transistor transconductance on operating current.

We discussed the basics of bipolar transistors in *Circuit Surgery* in July and August 2019, which may be helpful if ideas such as operating point in the following discussion are not familiar.

The collector current of a bipolar transistor is related to the base-emitter voltage by the equation:

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$

Here, I_S is the base-emitter junction saturation current and V_T is the thermal voltage – parameters which occurs in many semiconductor equations. The gain of the transistor in terms of input-voltage to output-current is called 'transconductance' (symbol g_m). This varies with the operating point (bias value of I_C). We can find the transconductance graphically by plotting I_C against V_{BE} and finding the slope of the graph at the operating point. We do the same algebraically by differentiating I_C with respect to V_{BE}. If you have studied calculus you will know (or may recall) that differentiating exp(k*x*), where k is a constant gives kexp(k*x*). After differentiating the above we can substitute for the expression for I_C into the result to get $gm = I_C/V_T$:

$$g_m = \frac{dI_C}{dV_{BE}} = \frac{I_S}{V_T}\exp\left(\frac{V_{BE}}{V_T}\right) = \frac{I_C}{V_T}$$

This shows that if we apply an input voltage directly to a transistor then the output current will be proportional to I_C/V_T times the input voltage. If I_C is controlled by a second input voltage, then the output will be proportional to the product of the two voltages.

A possible implementation of this idea is shown in Fig.9. This is based on the differential amplifier, which we discussed in detail recently (September 2020) – it is suggested that you read this first if you are not already familiar with these circuits.

In place of the fixed current source, which would usually provide the operating current to the emitters of Q1 and Q2 we have Q3 and R3, which are driven by input voltage V_Y. If the value of R3 is such the voltage dropped across it is much larger than the V_{BE} of Q3, then the emitter current supplied to the differential pair (I_E) will be proportional to V_Y (note that $I_E = V_Y/R3$). The output of the differential pair with respect to V_X is $g_m V_X$. As just discussed, g_m is proportional to this bias current (I_E in this case, specifically $gm = I_E/2V_T$, the factor 2 arises because I_E splits between the transistors), so the output is proportional to $V_X V_Y$, and thus the circuit acts as voltage multiplier.

The circuit in Fig.9 has a number of deficiencies, which means that it is not a particularly good multiplier. For example, the output depends on V_T and so it depends on temperature, and V_{BE} drops cause offsets, which vary with input voltage. The Gilbert cell multiplier overcomes these problems and provides a much more linear and temperature independent output.

Gilbert cell multiplier

Before looking at the full multiplier, consider the circuit in Fig.10. This is a pair of cross-connected differential amplifiers sharing load resistors. Assume bias currents I_{E1} and I_{E2} are equal. The two differential amplifiers operate normally, that is a non-zero input voltage difference (V_{IN}) will cause the bias to split unequally between the transistors in the pair, which normally results in a change in output voltage. However, here the two pairs are cross-connected and share resistors, so the effect of each pair on the resistor currents will be equal and opposite. Therefore, changes in input voltage have no effect on the output (the output difference, V_{OUT} on Fig.10, remains zero, irrespective of V_{IN}).

If the two bias currents in the circuit in Fig.10 are not equal, then the output currents from the two differential pairs will not exactly cancel and a change in V_{IN} will result in a change of V_{OUT}. The more different the bias currents are, the greater the output change will be. More specifically, the circuit behaves as a differential amplifier whose gain is proportional to the difference between I_{E1} and I_{E2}. The gain can be positive or negative, depending on which bias current is larger.

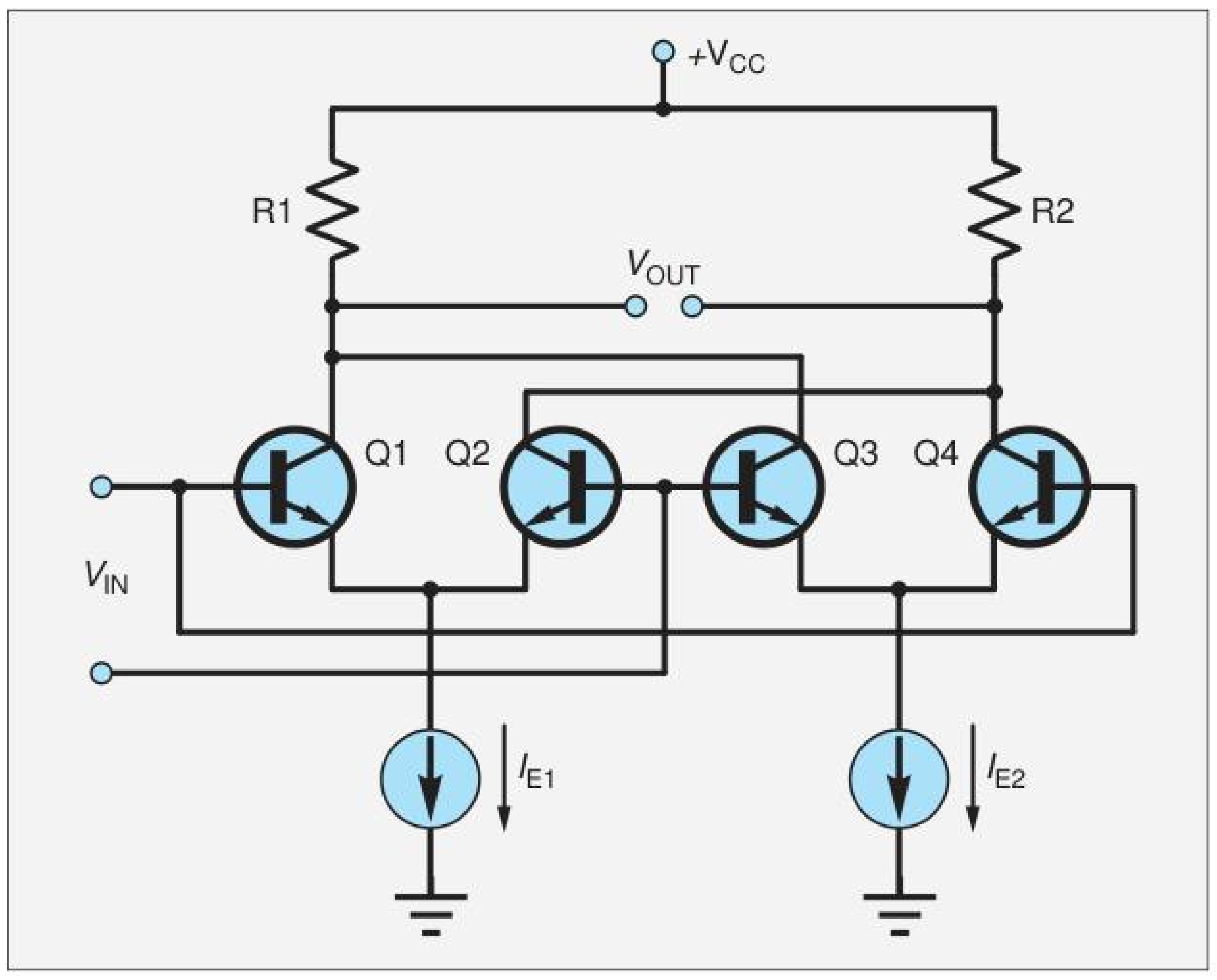


Fig.10. Cross-coupled differential amplifiers.

To complete the voltage multiplier, we need a circuit to convert a voltage to a current difference – this is exactly what a differential amplifier does, so we just need another differential amplifier added to the circuit in Fig.10 to make a multiplier. This circuit is shown in Fig.11. The output voltage (V_{OUT}) is proportional to $V_X V_Y$. This circuit, or variations of it, is widely used in integrated circuits.

Analogue mathematical operations can be built with discrete op-amp or transistor circuits, but there are also ICs available which perform multiplication, and which are likely to deliver higher performance than discrete versions. One example is the AD835 250MHz, Voltage Output 4-Quadrant Multiplier from Analog Devices.

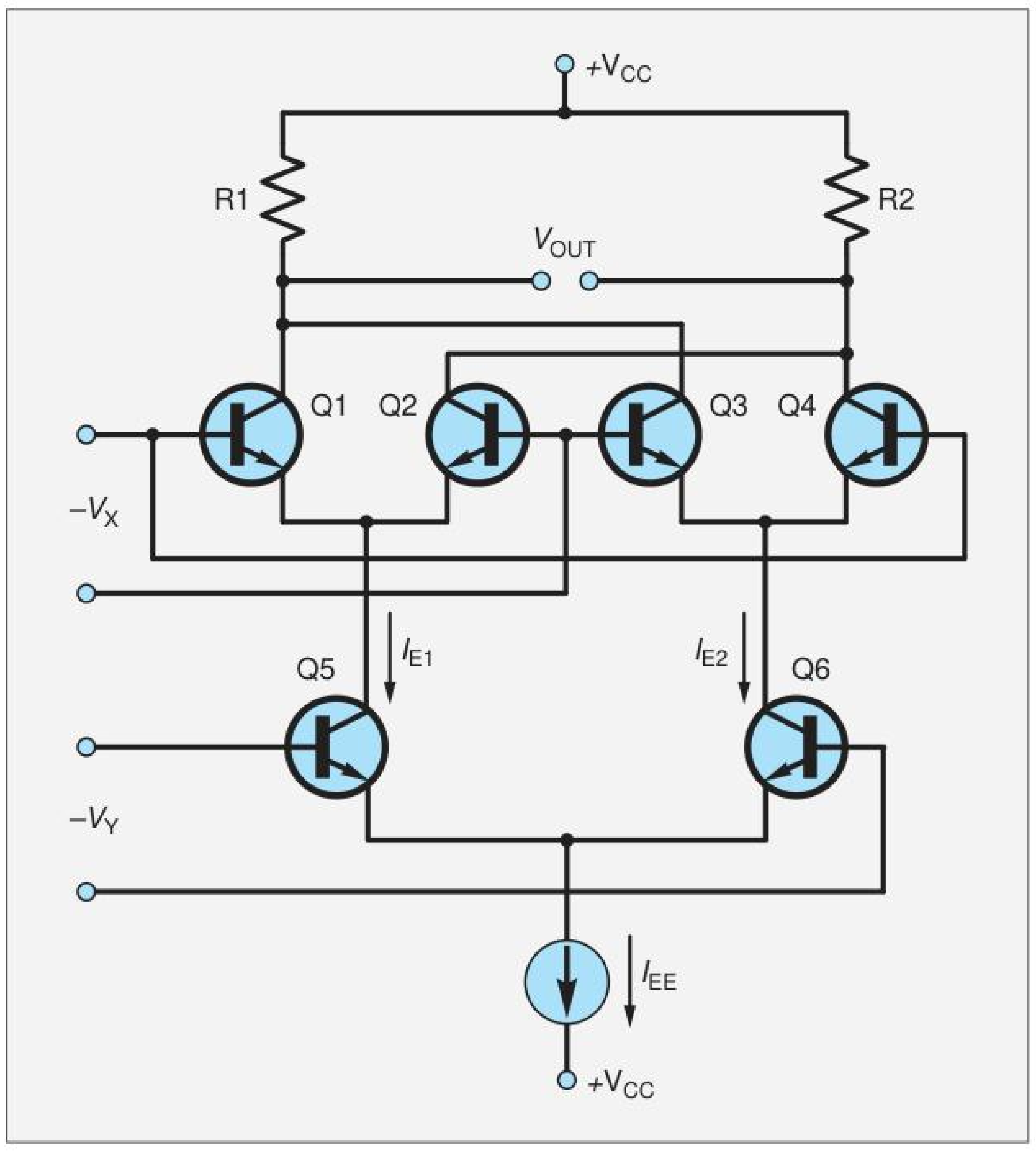


Fig.11. Gilbert cell multiplier.

Practically Speaking

Hands-on techniques for turning ideas into projects – by Jake Rothman

Restoring old equipment – Part 1

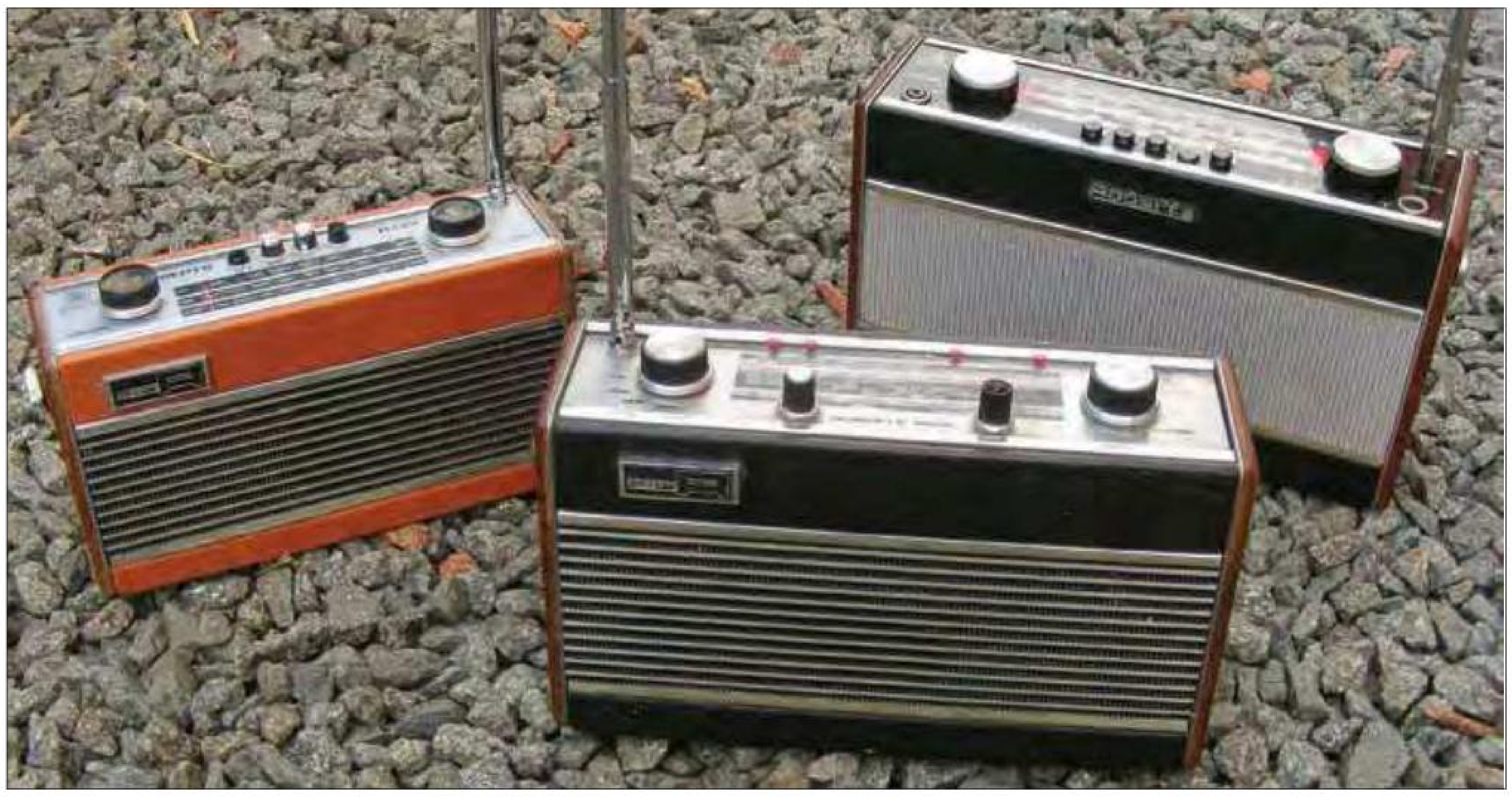


Fig.2. A selection of old Roberts transistor radios – we'll be doing them up soon.

This is the start of a series about restoring old and vintage electronic equipment. Before we proceed it's worth asking an important question. Given the throwaway nature of so much modern electronics, is restoration worth it? Well, that depends on many factors. If it has historic value, this can be sufficient to justify a restoration well beyond an economic repair. Organisations, such as The National Museum of Computing at Bletchley Park and the Museum of Science and Industry in Manchester, rely on vintage-electronics experts, because preservation is at the core of their work (and also, working exhibits attract more visitors!). I remember blagging free entrance for myself and a few teenagers to Bletchley Park by offering a bag of Mullard OC42 transistors to help restore an old computer.

Sometimes, restoring electronic equipment is part of a larger restoration program. Enthusiasts have painstakingly replicated 1960s electronic control cards for an English Electric diesel locomotive (Fig.1). Heritage railways and curators of cold-war-era V-bombers have to have their old-world electronics operational.

The driving force to restore is often deeply nostalgic and personal. All engineers have formative childhood experiences that set them on the path to designing their own equipment. It was gazing down at the electronic 'city' of glowing valves through the ventilation slots of 1960s TVs that set me off on a lifetime of electronics, aged six. Also, Grandad's polished wooden radiogram with a Roger's valve amplifier and Wharfedale loudspeaker emanating the strings of Albinoni's Adagio kicked off the Hi-Fi bug in me. Upon inheriting his pride and joy as a teenager, I promptly pulled it all apart to see how it worked!

Some items are iconic British brands; for example, Quad, Leak and Vox guitar amplifiers, for which there will always be a demand. Before globalisation, many countries had their own national electronic brands, fostering a sense of tradition and place, further feeding nostalgia. In Denmark, it's B&O, in the Netherlands it's Philips and in Japan it's Sony. I could go on, but what British readers of a certain age cannot identify with a happy childhood memory of a Robert's or Bush playing radio in the kitchen? (see Fig.2). Just the mention of a Mullard EL84 audio output valve or a germanium OC71 transistor brings it all back.

Whatever your motivation for restoration there is no doubt that it is a great way to learn hands-on electronics and troubleshooting. I certainly picked up a huge amount of knowledge about how to build and design equipment, plus a lot of insight into how not to build things!

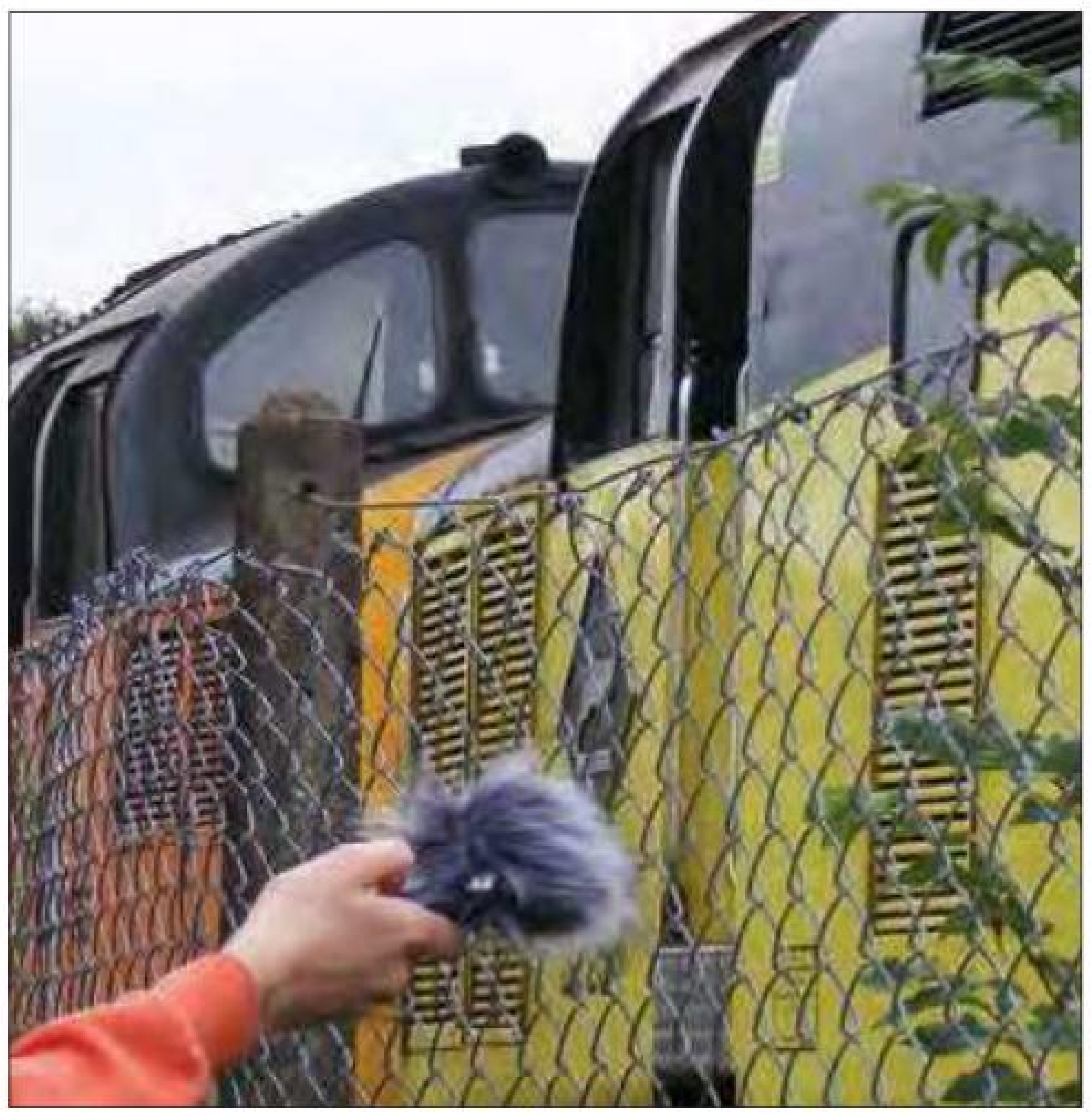


Fig.1. Who's going to keep the early 1960s electronics going in these old locos? (They produce excellent sound for sampling!)

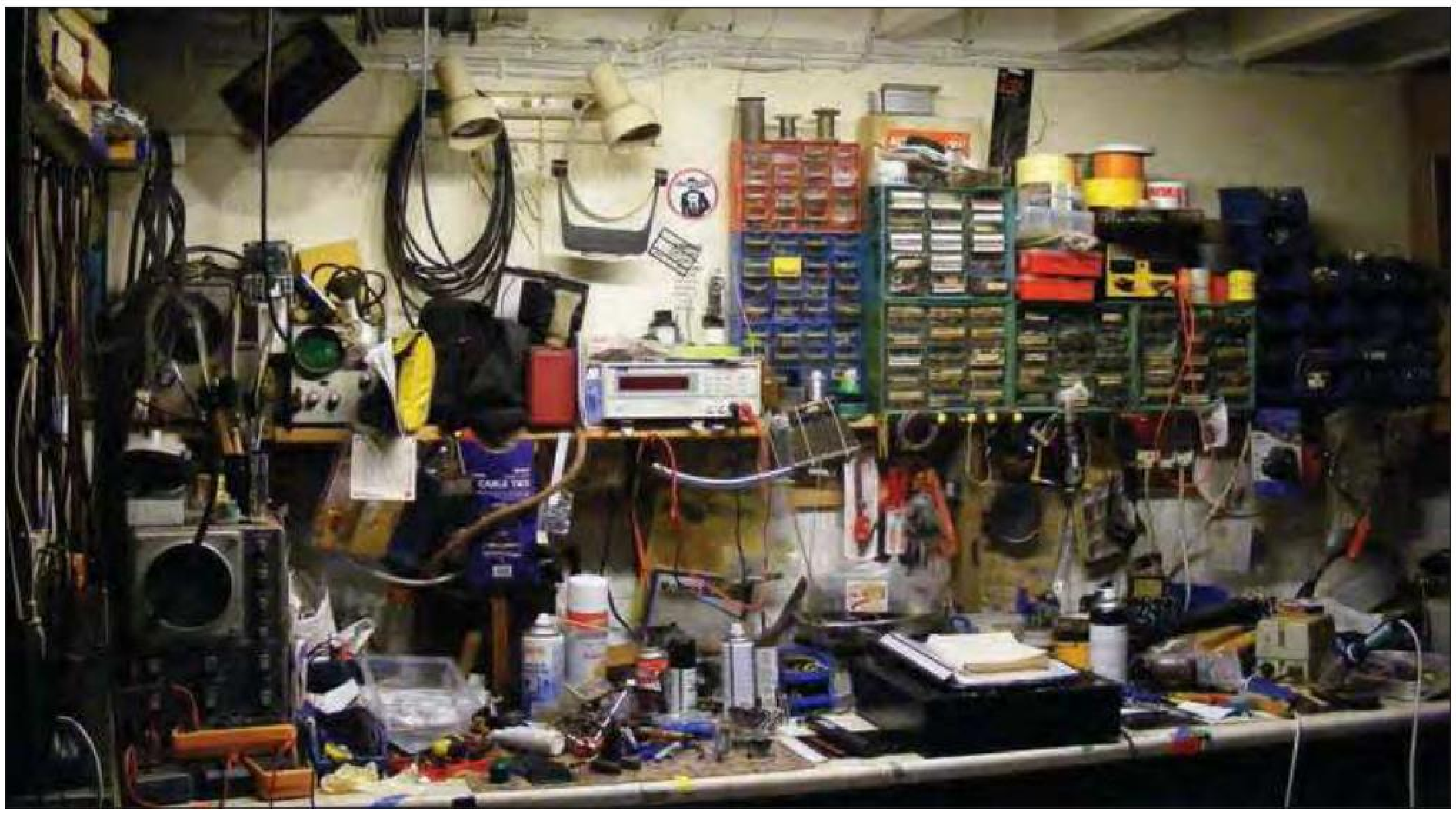


Fig.3. A restorer friend's workshop; note the stack of aerosols and minimal test gear.

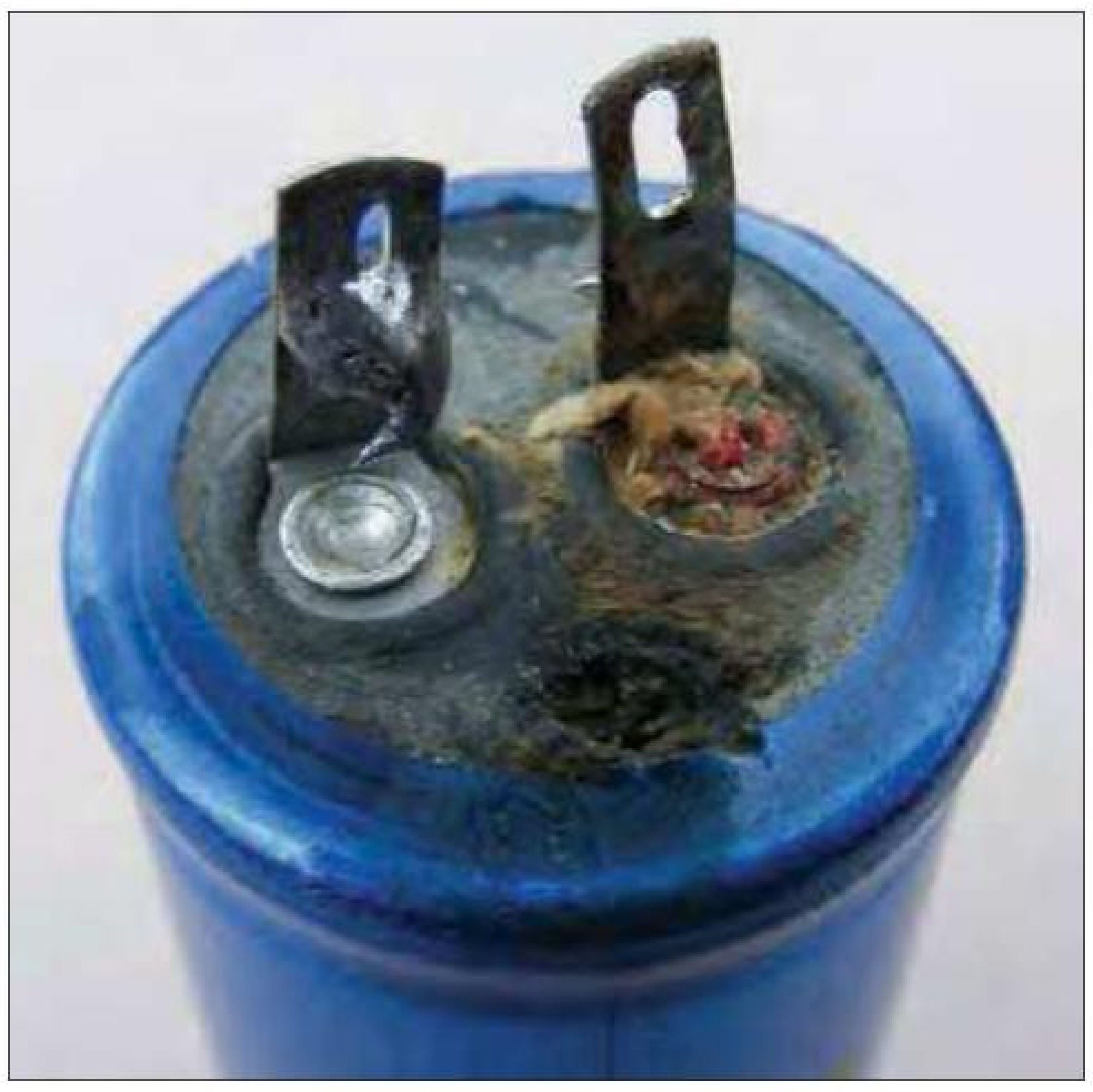


Fig.4. Old components usually fail visually. This smoothing capacitor's safety vent has clearly blown.

Restoration work is essentially practical, an electronics degree is not required and is possibly even a hindrance. I know many people who effectively restore equipment, knowing very little electronic theory and not even using circuit diagrams. This is achievable because many faults on old technology can be found simply by visual inspection (see Fig.4) and good old 'swapnostics' – find a broken part and just swap it out. No fiddly software updates needed for old gear.

Component issues

One of the biggest challenges facing would-be restorers is sourcing parts. Entropic ageing processes, damp ingress, heat, dust, oxidation and leakage reduces many electronic components to scrap in old equipment. Plenty of past components, such as resistors, transistors and capacitors are simply inferior to modern designs. Carbon-composition resistors drift high with age, germanium transistors had relatively bad die processing and contacts. Poorly sealed electrolytic capacitors dry-up and paper dielectric capacitors (Fig.5) go low resistance. When restoring a piece of equipment over 30 years old, expect to remove a large pile of such parts. The pile of failed parts shown in Fig.6 was from a Leak Stereo 30. A typical resistor problem is shown in Fig.7.

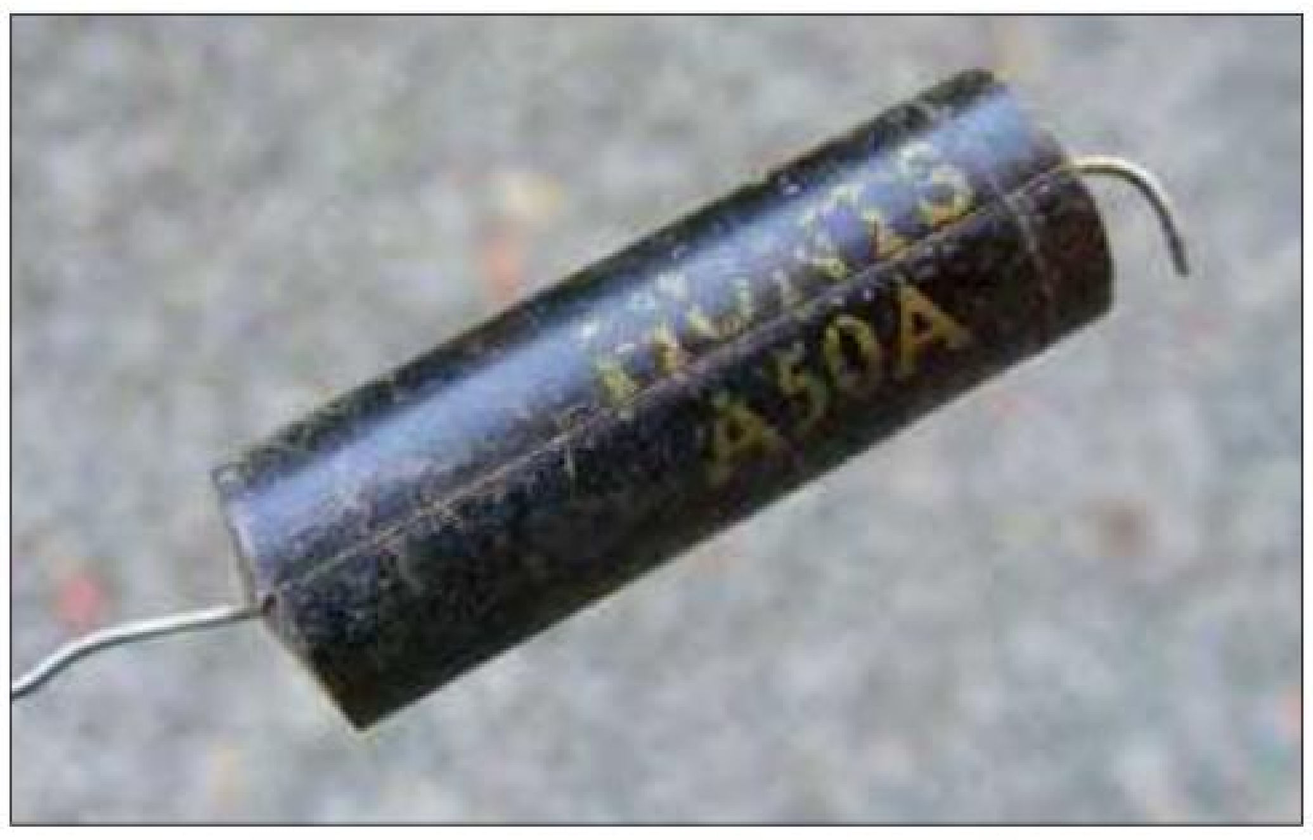


Fig.5. Old paper capacitors often leak electrically. I find anything made by Hunts seems to be particularly unreliable.

New LEDs for old lamps

The problem of parts leads to one of the biggest quandaries for a budding restorer. There are two approaches to take; restore using 'original', possibly poor-quality parts, or use new ones, that will look completely wrong. Here one may start redesigning the unit, which is a mistake many educated engineers make. I regret doing this myself to Quad II valve amplifiers. First, it destroys history; and second, the effort is better channelled into a completely new design. If the radio dial was illuminated with warm incandescent light bulbs, don't 'upgrade' it with blue LEDs. True enthusiasts have been known to stuff new plastic-film capacitors into the cases of old paper capacitors where the correct replacement is unobtainable. If you do 'improvements' make sure they are reversible. If you have to substitute transistors, keep the old blown ones for historical completeness – a museum or collector may thank you for it. *Tower's International Transistor Selector* is the best book for optimising transistor substitutions. There are PDFs online available from the Internet Archive and Google docs.

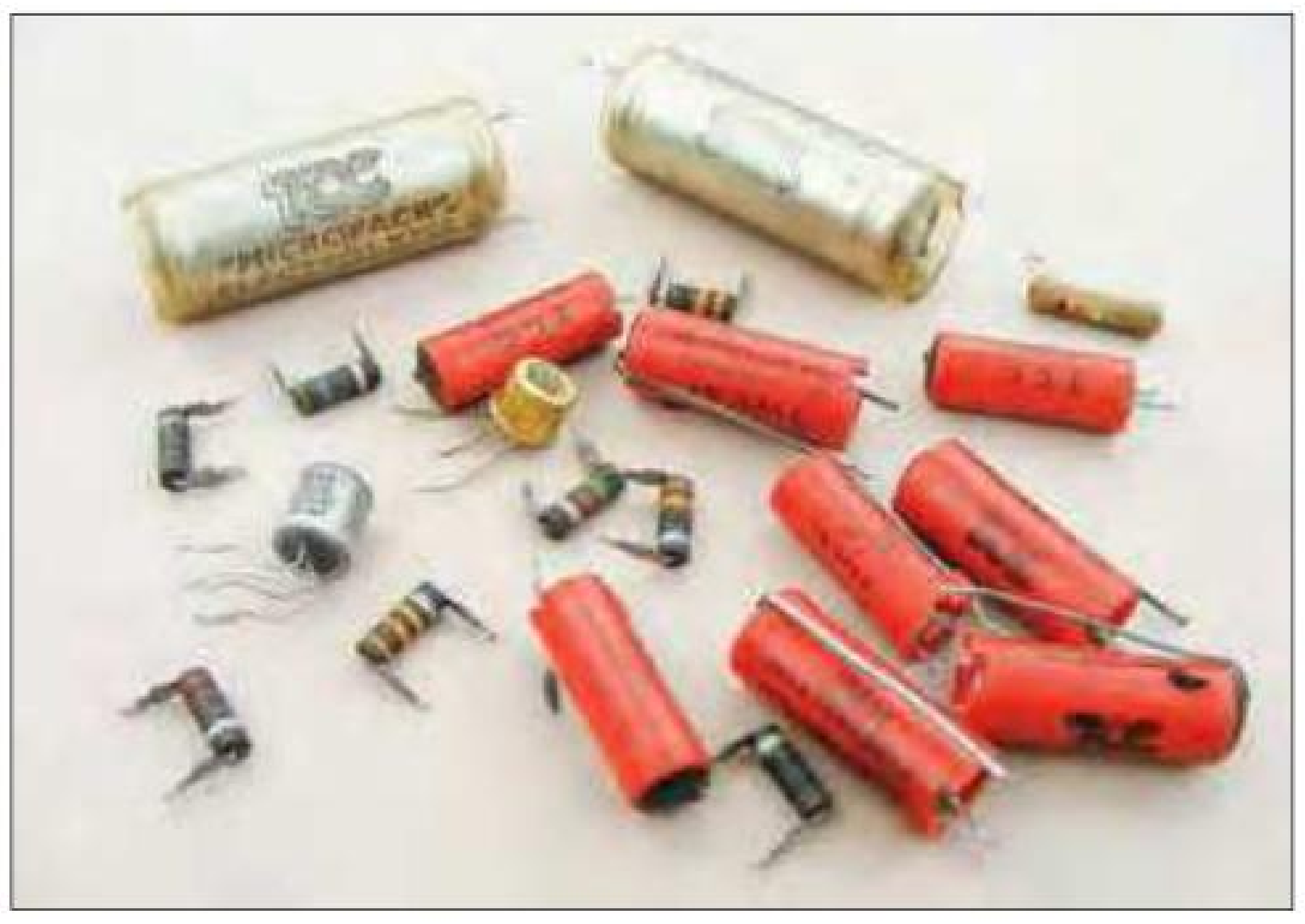


Fig.6. A pile of faulty components taken out of a 56-year-old Leak stereo 30 amplifier. Surprisingly, the output transistors were fine.

NOS – 'New Old Stock'

Watch out when buying 'vintage' or new-old-stock components. If they have been stored for 50 years then there will be a fail rate of at least 10%. The moral, buy more than you need for the repair. I found an unopened box of 200 germanium diodes dated 1963 (see Fig.8). Upon cutting the animal glue paper-tape seal I could smell the coal smoke from the steam goods train they probably travelled on, a pure olfactory nostalgia trip. A particular problem with NOS germanium transistors is 're-marks'. This is because manufacturers in the 1960s and 70s sold their rejects on the open market to companies like Bi-Pak Semiconductors and Bi-Pre-Pak Ltd (Fig.9) They were usually just unmarked metal cans, until some enterprising people bought labelling machines and sold the devices on. However, the game is usually given away by the large font size and lack of manufactures markings and date codes, as illustrated in Fig.10. I have found re-marks to be especially

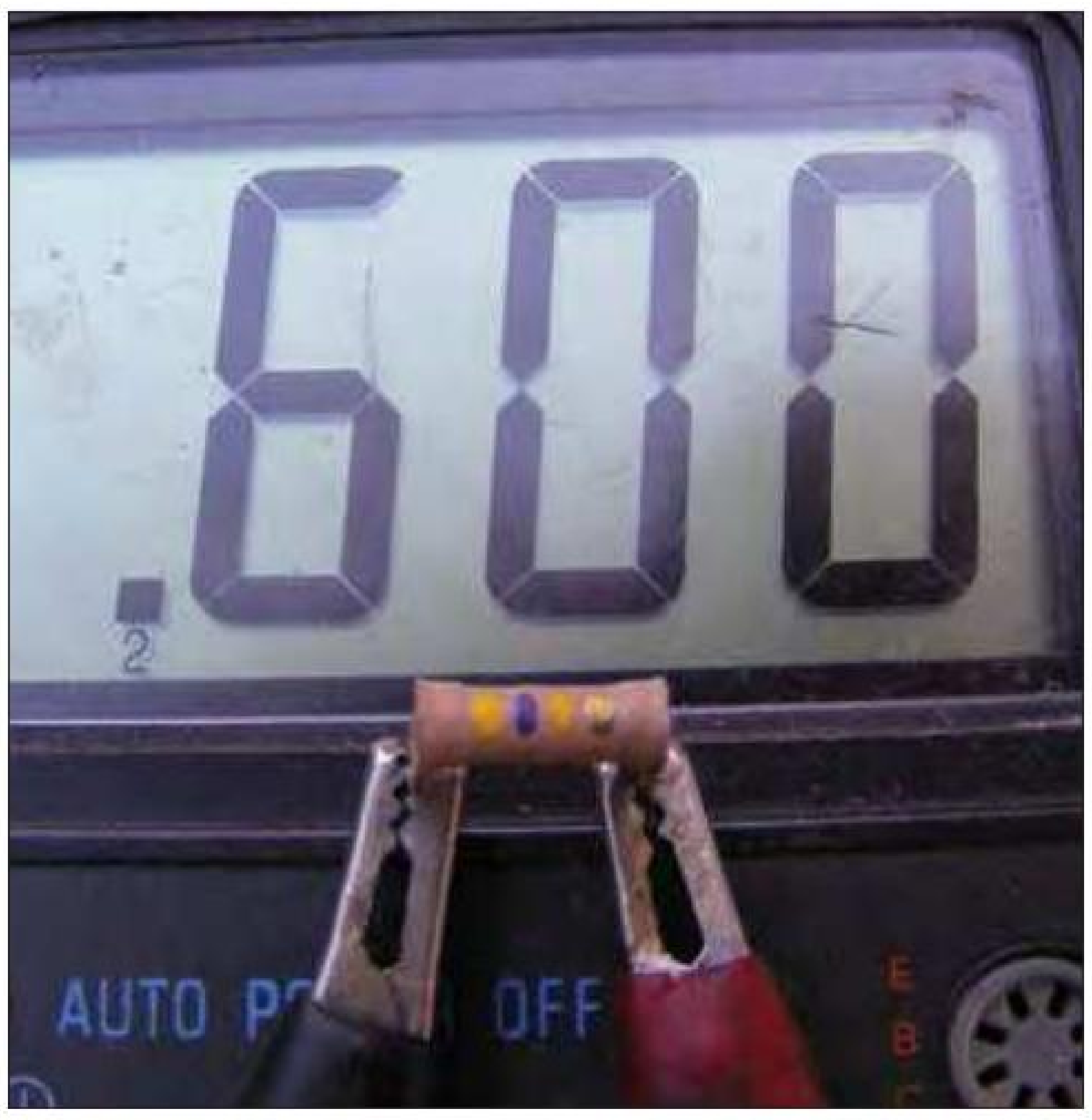


Fig.7. Carbon composition resistors are prone to go high in value with time, especially values above around 10kΩ. These Erie 'pluggable' types are especially prone. This one has gone from its stated value of 470kΩ 5% to 600kΩ.

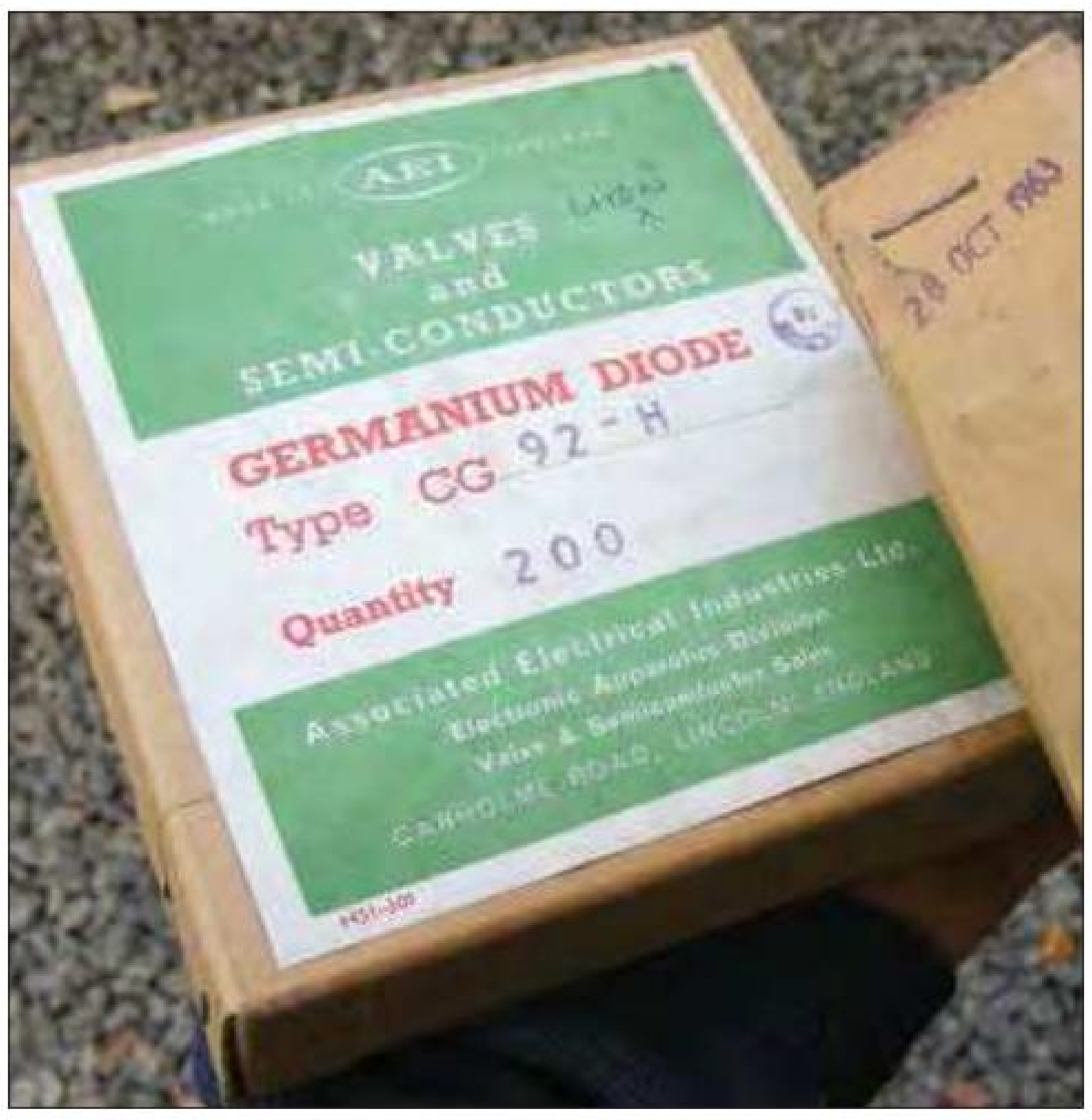
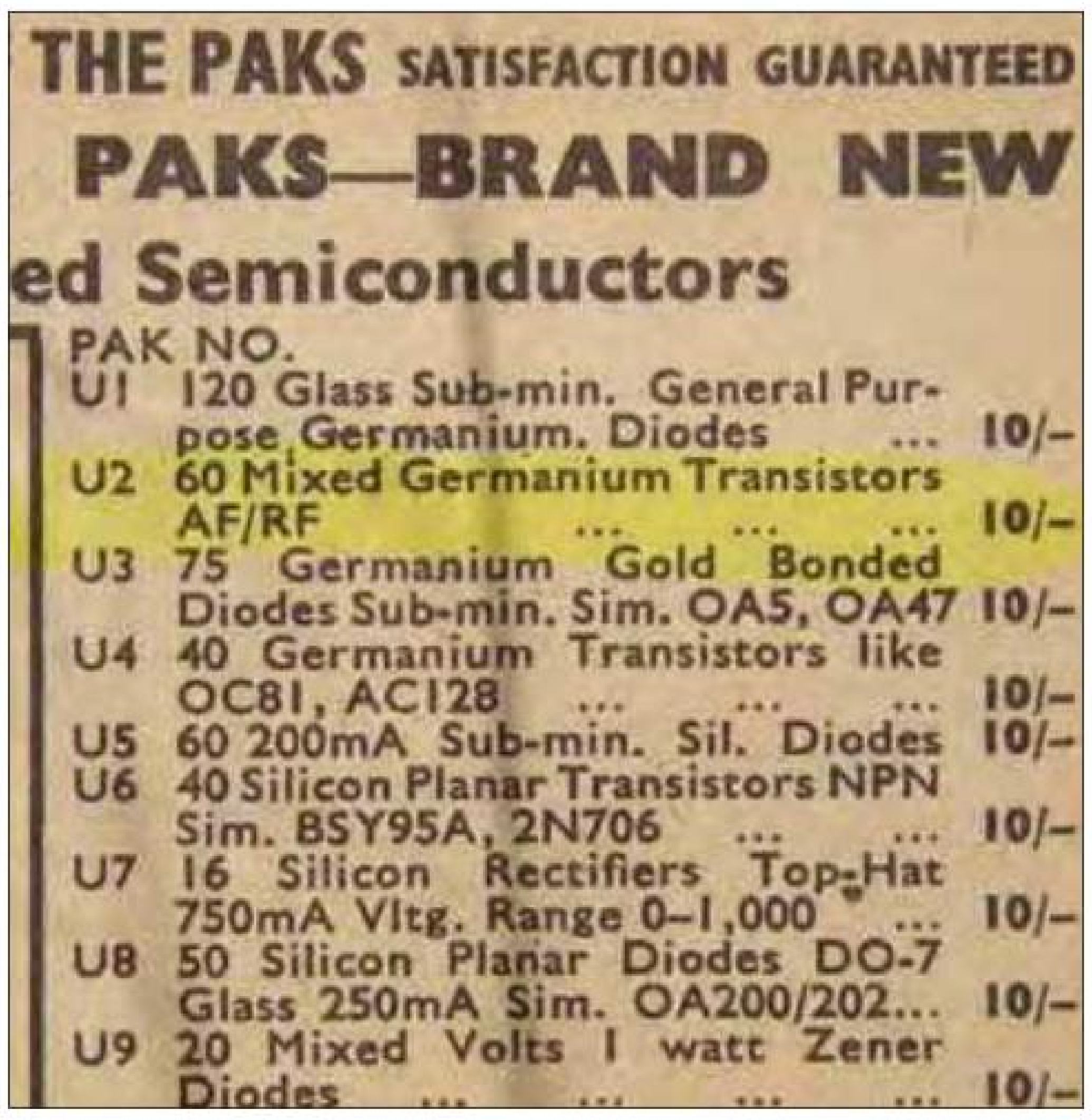


Fig.8. A box of CG92 germanium diodes from 1963. When opened I could smell the sooty sixties. I bought these from John Birkett's electronics shop in Lincoln in 2010. He's still trading and has still got some in stock.



THE PAKS SATISFACTION GUARANTEED

PAKS—BRAND NEW

ed Semiconductors

PAK NO.		
U1	120 Glass Sub-min. General Purpose Germanium. Diodes ...	10/–
U2	60 Mixed Germanium Transistors AF/RF	10/–
U3	75 Germanium Gold Bonded Diodes Sub-min. Sim. OA5, OA47	10/–
U4	40 Germanium Transistors like OC81, AC128	10/–
U5	60 200mA Sub-min. Sil. Diodes	10/–
U6	40 Silicon Planar Transistors NPN Sim. BSY95A, 2N706	10/–
U7	16 Silicon Rectifiers Top-Hat 750mA Vltg. Range 0–1,000 ...	10/–
U8	50 Silicon Planar Diodes DO-7 Glass 250mA Sim. OA200/202...	10/–
U9	20 Mixed Volts 1 watt Zener Diodes	10/–

Fig.9. A Bi-Pak Semiconductors ad from the September 1968 issue of *PE*. These dodgy devices are still circulating on eBay and cost around £3 each, rather than the original 10/- (50p) for a pack of 60 germanium transistors.

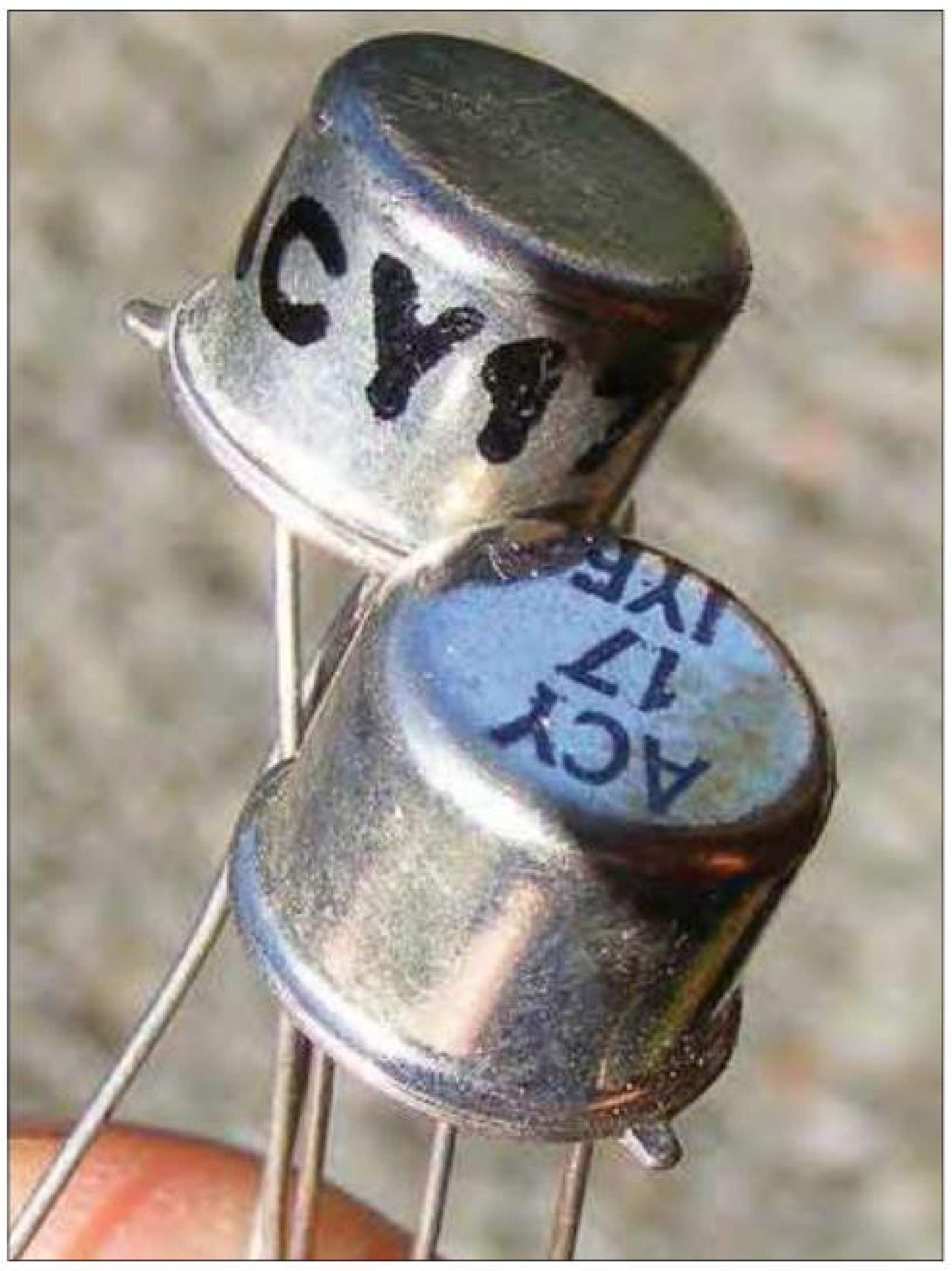


Fig.10. A remarked (top) versus genuine (below) ACY17 high-voltage germanium transistor. Test the remarked device thoroughly for leakage, H_{fe}, max V_{cb} and noise before using.

common on eBay and at radio rallies. Often the vendor is genuinely unaware there is a problem.

Digital test gear

The most important thing to have is a DMM/multimeter to measure voltages, current and resistances. An oscilloscope is pretty essential for setting up power amplifiers properly. (Although many audio restorers do a successful job by ear.)

If you really want to get moving, digital innovation has come to our rescue. I remember back in the early 1990s I met Jeremy Siddons of Peak at the Buxton Audio Constructor's Show. He had his design for a transistor tester that gave the pin-outs and test data for any transistor connected to it. I stuck it on some old OC22 power transistors and it identified them as germanium and most importantly gave the leakage current and a true H_{fe} reading. I said he would do brilliantly with that design, and he did. Nowadays, we all now know his company as 'Peak Electronic Design', and I reckon his semiconductor and electrolytic ESR testers have saved more electronic equipment from going to landfill than any environmental initiative. One only has to observe all the YouTube presenters, such as Radiocruncher, who use them regularly (see: **http://bit.ly/pe-nov20-crunch**). Fig.11 and Fig.12 show my Peak testers being used.

The Internet has of course revolutionised renovation and repair. It's become highly effective for sourcing advice, photos and circuit diagrams.

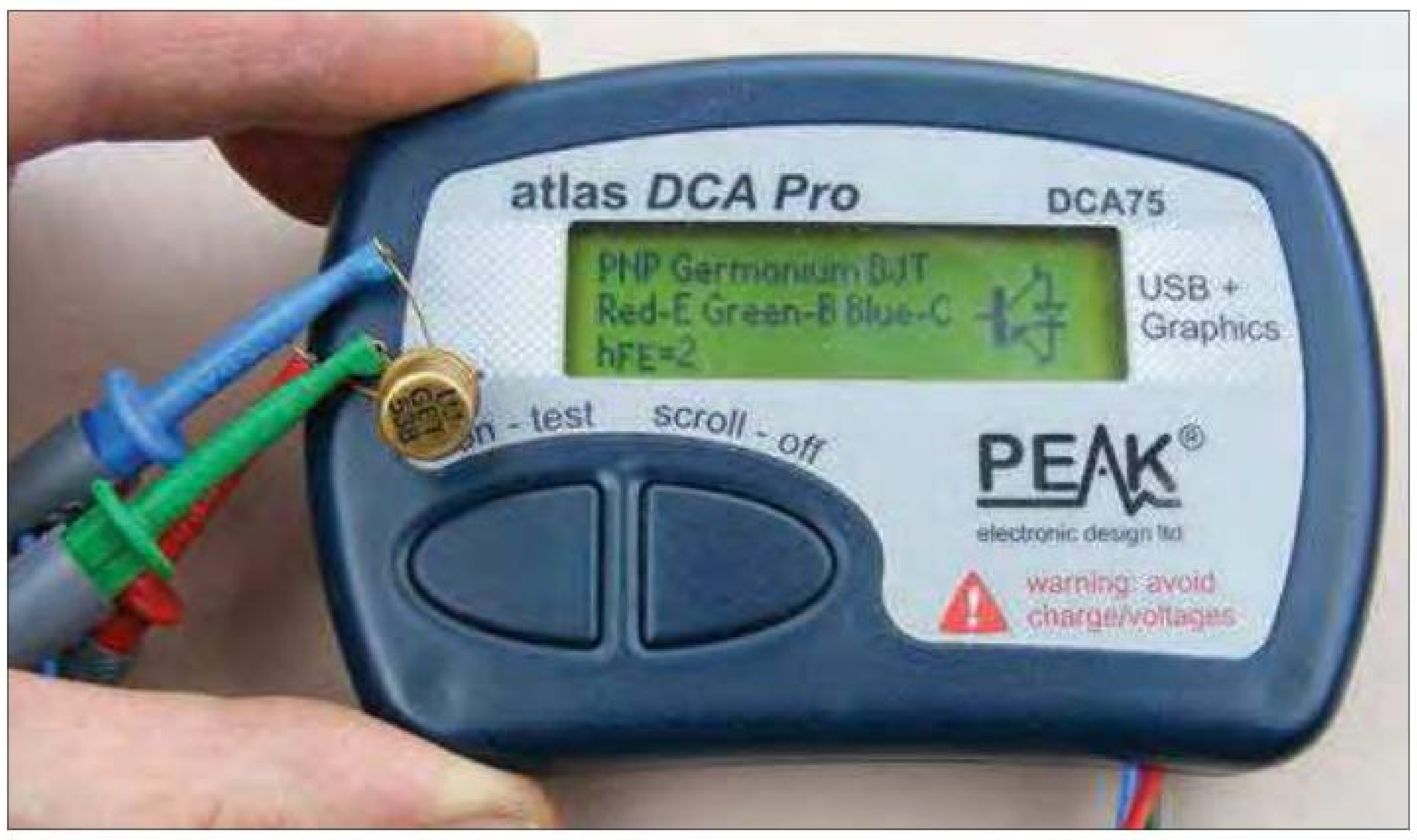


Fig.11. The Peak transistor tester is a godsend for all repairers. What use is a transistor with an H_{fe} of 2?

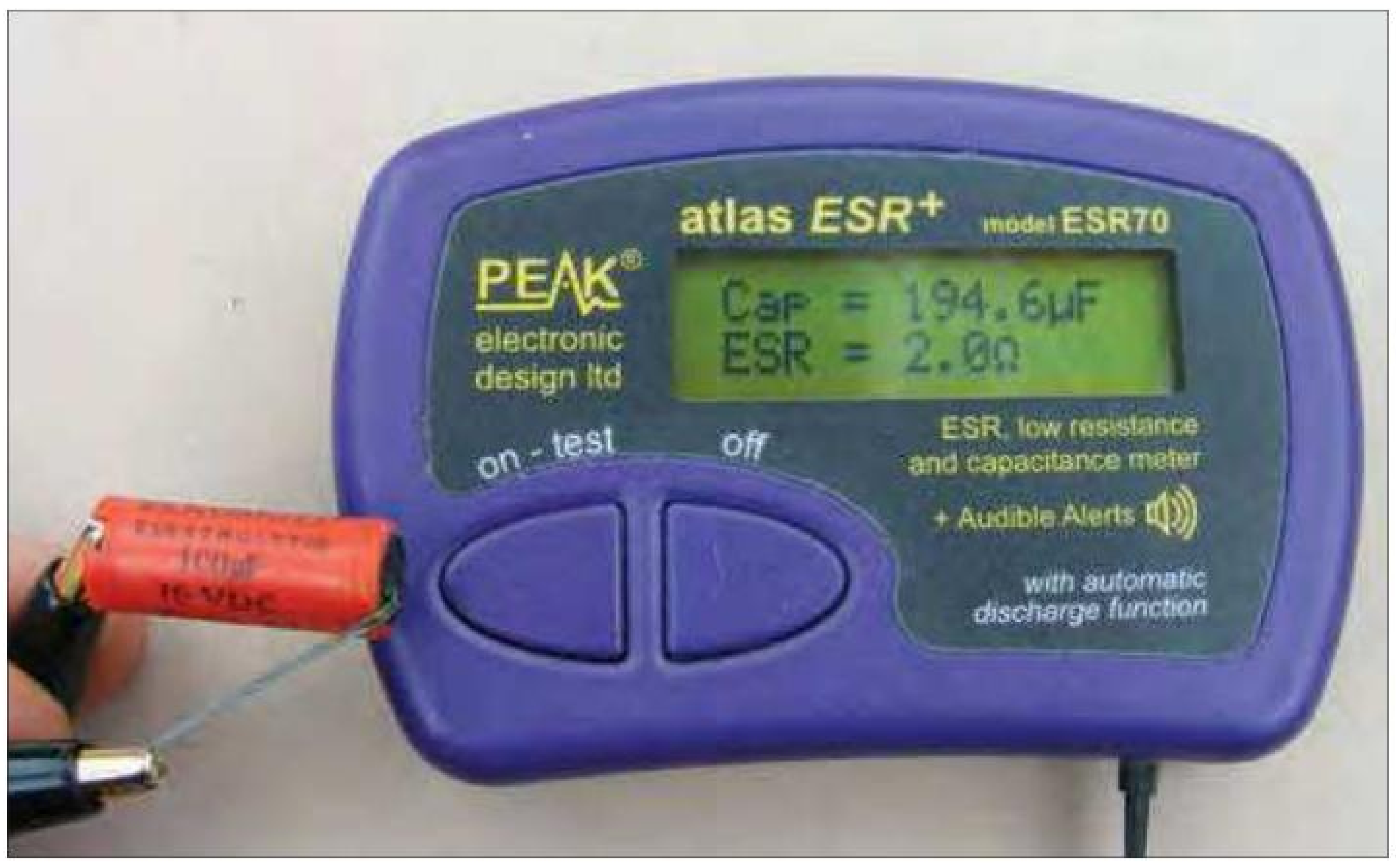


Fig.12. The Peak ESR tester is great for detecting dried-out electrolytic capacitors. It can test capacitors that are still soldered into the circuit. No need to push buttons; it resets as you move from one capacitor to another. A cost-effective device for all restorers. Here the capacitor will work fine, despite drifting high.

Old can be better

Sometimes a restored audio product is preferable to a new one. For example, old Roberts FM radios have cases made out of wood, giving a much better sound quality than a modern plastic minimal bit-rate DAB equivalent. I'd draw the line though at watching a 4K Netflix movie on a 405-line 1964 black and white Bush TV! However, should you wish to, there are HDMI-to-405-line converter interfaces available. The National Science and Media Museum in Bradford may have commissioned some from British Vintage Wireless Society members.

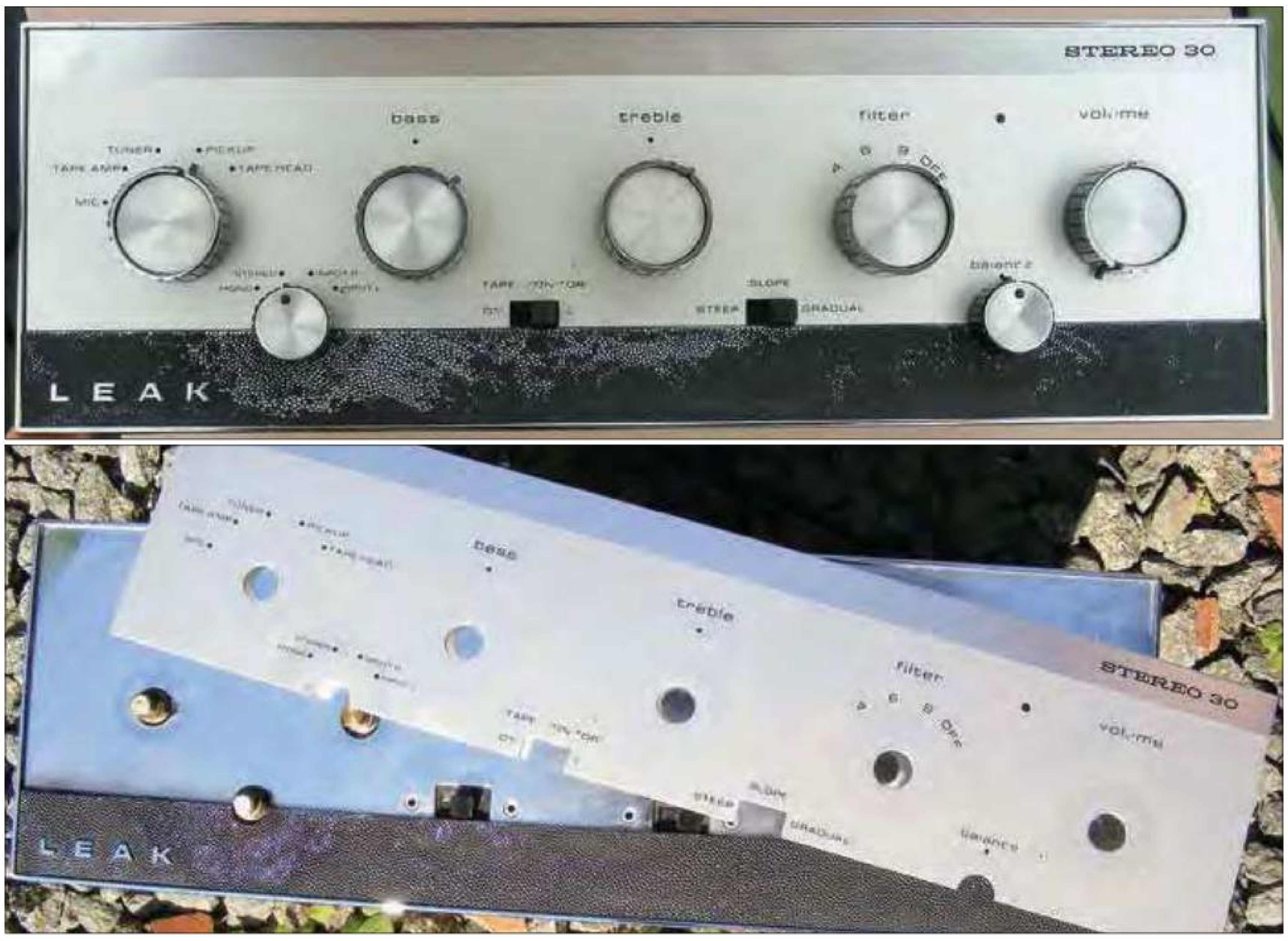


Fig.13. Leak Stereo 30 front panel: take the knobs off and remove for ease of cleaning.

Their magazine has some of the most beautiful restorations I've ever seen. There is also the fact that the old stuff that has survived has been built to last and be repaired, something that has got lost in today's world of disposable tat. (See: **http://bit.ly/pe-nov20-bvws**).

The boring bit, cleaning and health & safety

The great thing about old gear is that it was designed to be built by hand, not automated processes, so it is easy to disassemble. However, this leads to the worst bit of restoration – cleaning! We all want to get straight to the electronics, but the dirt on old tech can be horrendous and has to be removed first. It also looks horrible, no one wants to see an old radio that's been on a shelf above a cooker for 30 years. Although I suppose you could get a Martin-Parr-style photo out of it first.

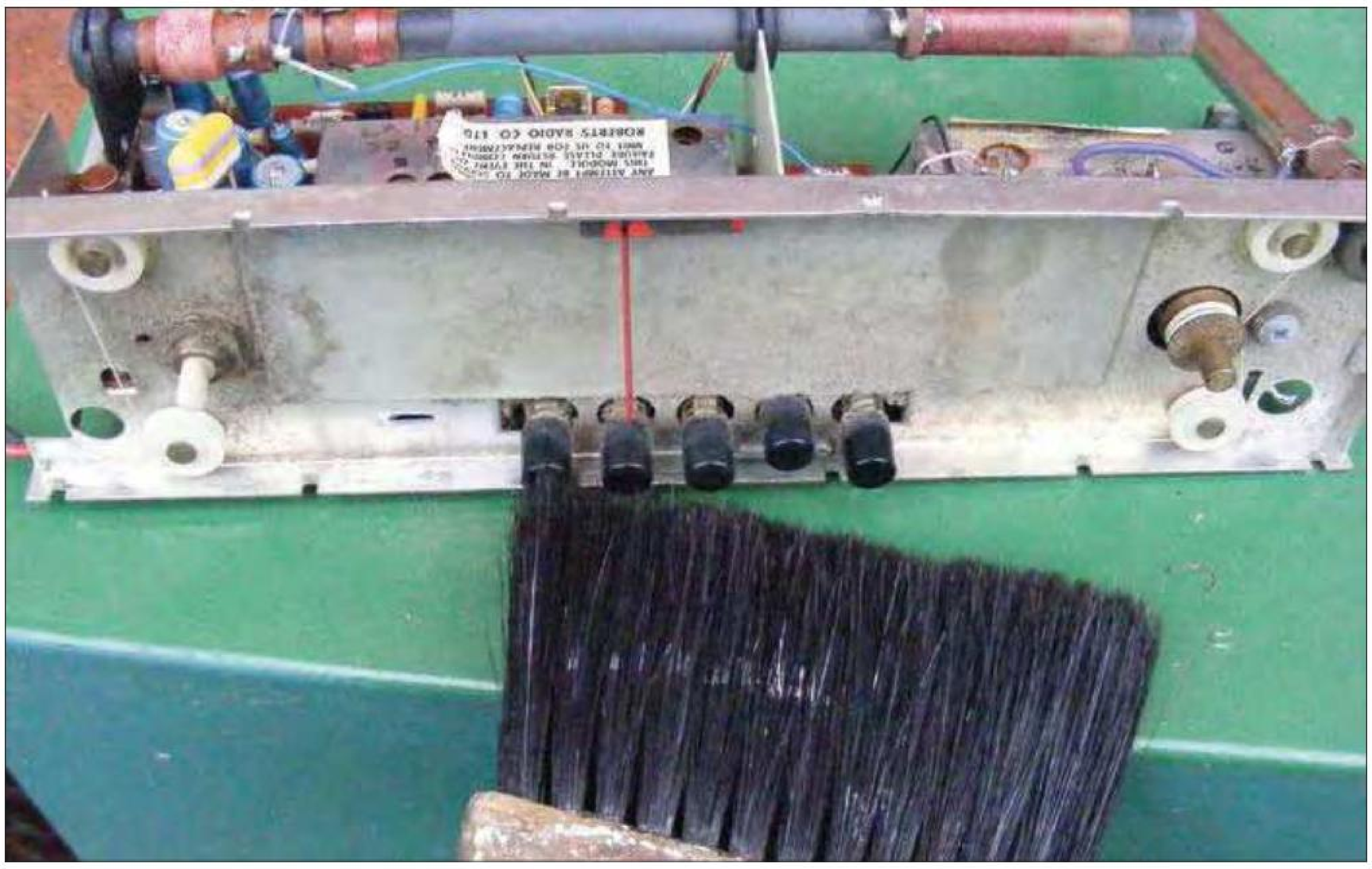


Fig.14. When disassembling, take the opportunity to clean normally inaccessible areas, such as the tuning drive under the panel of a Robert's R600 radio. A multi-tufted dusting brush is a vital tool.

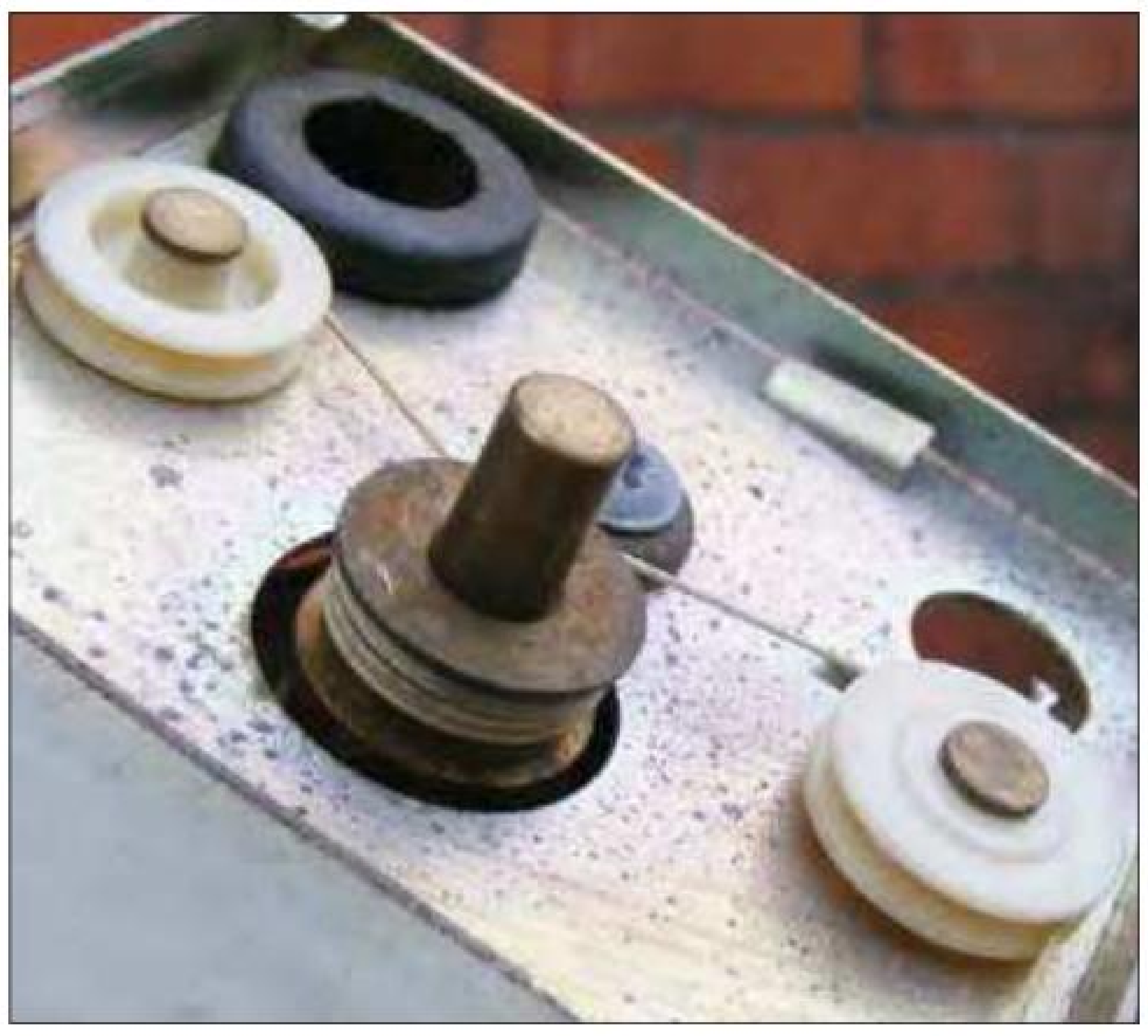


Fig.15. Roberts radio cleaned of dust – those pulleys are less likely to stick now.

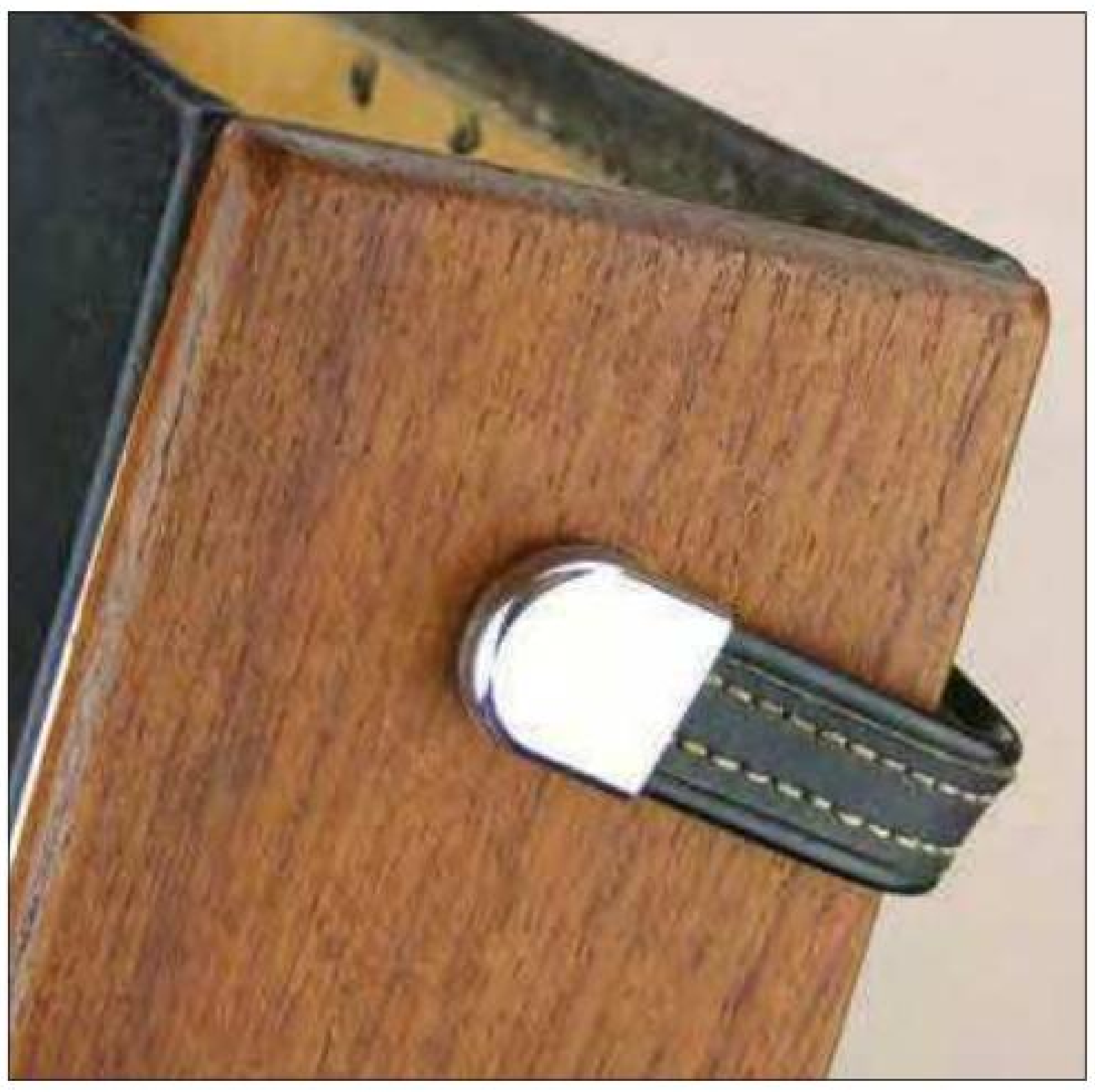


Fig.18. I just love teak end-panels on old 1970s consumer electronics. I've noticed Hammond Manufacturing have reintroduced these on a new range of cases. Rub in Danish oil, allowing six hours between coats to restore.

The first rule of cleaning front panels is always remove the knobs, as shown in Figs 13. Fig.14. shows the muck found under a tuning dial on a Robert's radio. To prize off push-on knobs I use a rounded table knife to get under the edge and gently lever up. WD40 can help with seized-on knobs and to make it easier next time I appy a little silicone grease (which never dries up) on the shafts.

I once bought some old BBC mixer modules from under the railway arches at M & B Radio in Leeds. Huffing and puffing I blew off loads of white powder from the innards only to find that they had come from an asbestos-filled attic in Armley near Turner & Newall's infamous factory. I hate to think how much rosin, lead, cadmium, PVC monomer and beryllium dust I've inhaled restoring old gear. I often hear the most horrendous cancers being discussed at radio rallies among 'senior' restorers. Acute myeloid leukaemia is significantly higher among people who work in the electronics industry. So do be careful: read labels, wear masks and wash your hands – you have been warned!

Once the toxic dust is off (Fig.15) it's time to get the organic solvents out, not carcinogenic ones! My favourite is good old IPA, not the beer, but isopropyl alchohol or propan-2-ol to give it its correct name, as shown in Fig.16. It is most effective for tackling old rosin flux residues. Luckily, this replaces the poisonous carbon tetrachloride trichloro ethane, benzene and other horror substances that would have graced any workshop in the 1970s.

For Perspex front panels (Fig.17) and the like it is fine to use washing-up liquid and water, though not a good idea to use near the electronics. Another favourite is label remover, especially the citrus-oil based type for removing sticky organic materials that IPA won't dissolve. Take care you don't remove component markings with solvents.

Danish oil is great for buffing up the teak wooden ends that grace so many 60s and 70s products, as shown in Fig.18. For the final hit, a Novus scratch removal kit, as used by motorcyclists for their polycarbonate visors, with its three grades of abrasive liquids is most effective for plastic panels such as meter bezels (**https://amzn.to/33MQKWP**).

That's enough scrubbing, screwing and sniffing. Next month, I'll get down to some real electronics as we start to restore a Leak Stereo 30; Britain's first successful Hi-Fi transistor amplifier, introduced in 1963.

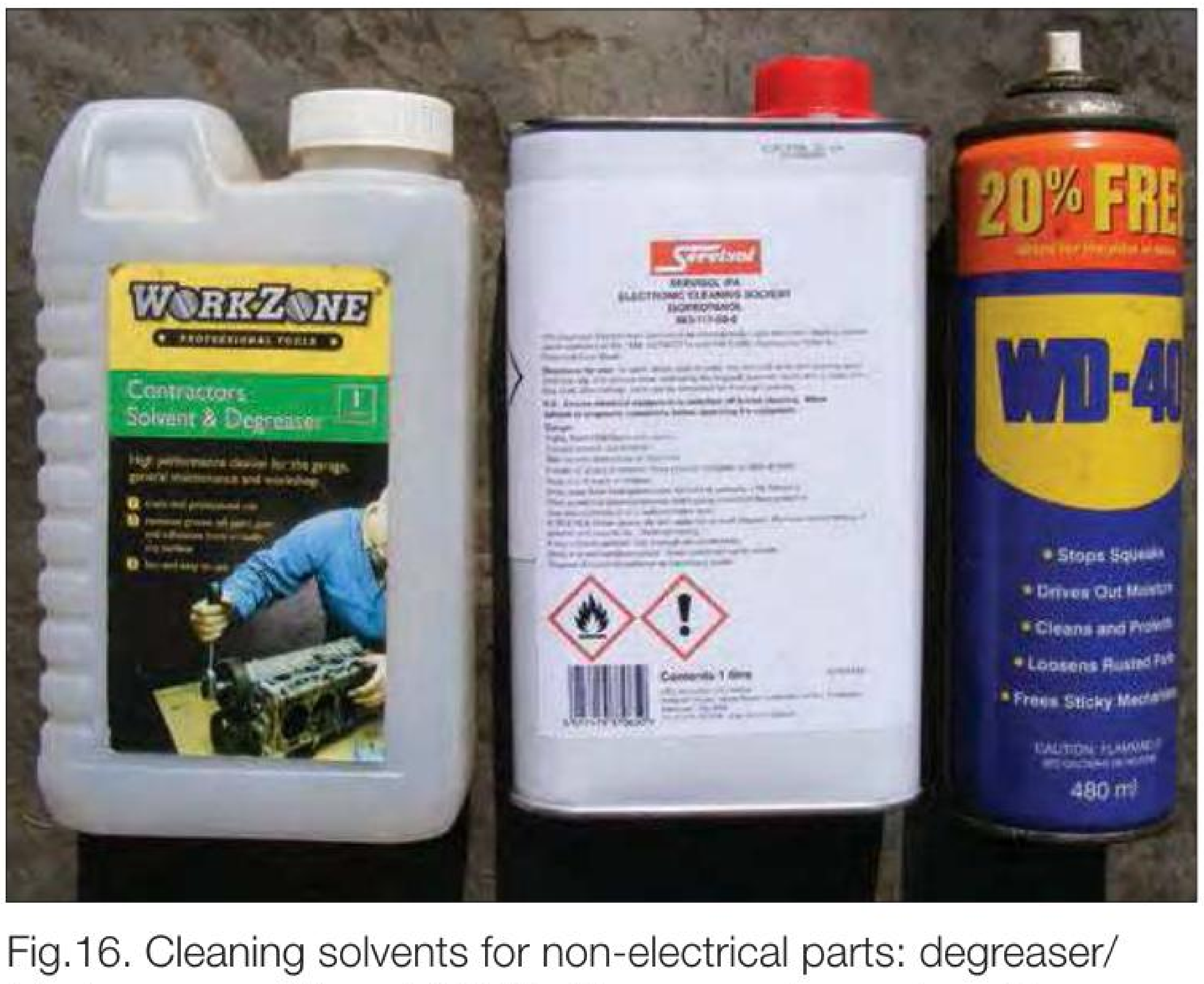


Fig.16. Cleaning solvents for non-electrical parts: degreaser/label remover, IPA and WD40. Also use water and washing-up liquid. We'll cover electrical contact cleaning next month.

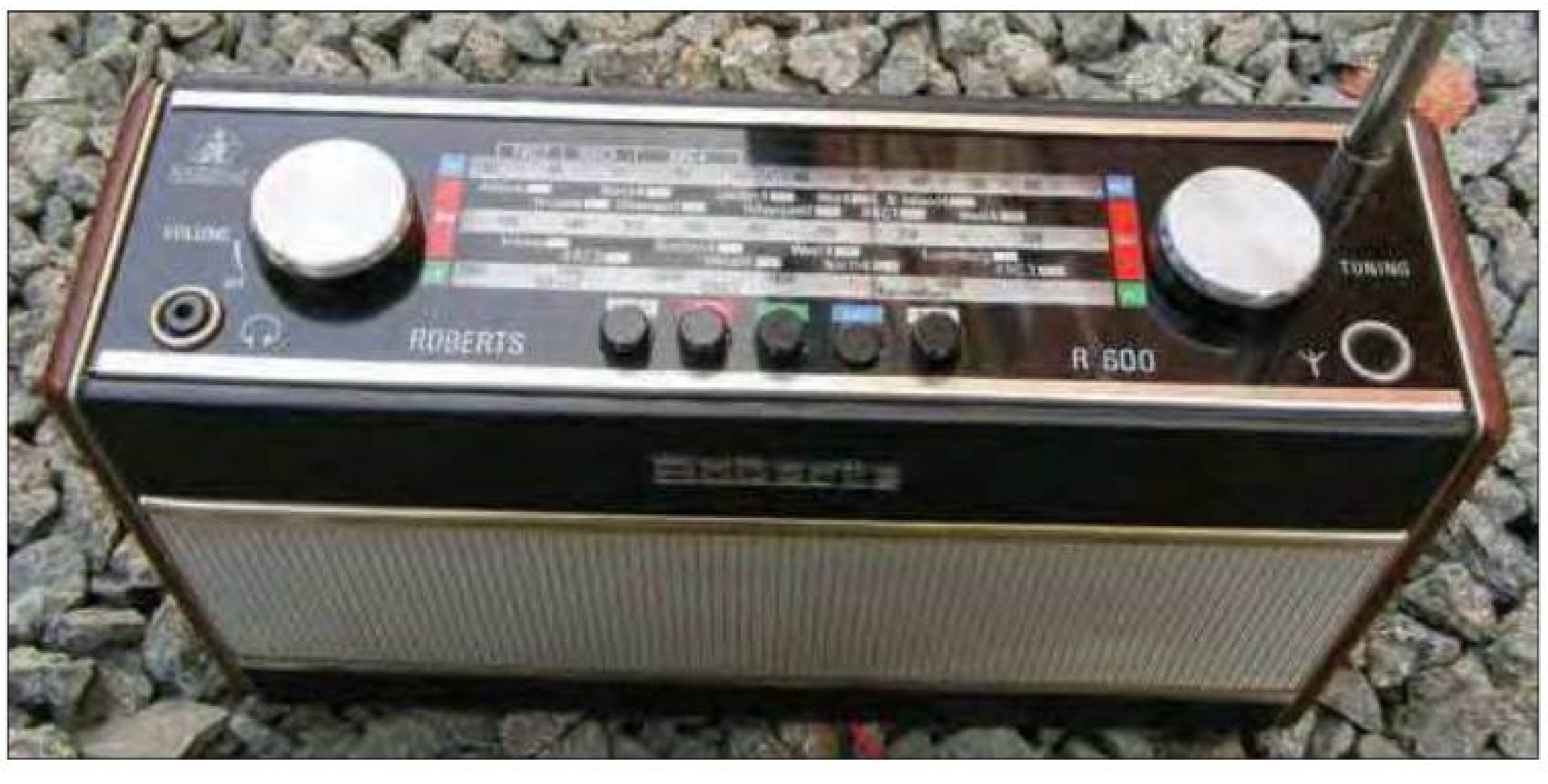


Fig.17. The cleaned Perspex front panel of a Robert's radio. Fill in the scratches in the back printing with black gloss modellers paint. Minor scratches can be removed with very gentle abrasives such as Novus scratch remover. The silver edging strips and knobs were all cleaned separately.

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 9

Well hello there! On the off chance you are newly arrived at this party, our current discussions pertain to one of my hobby projects – a 12×12 array of ping pong balls, each equipped with a WS2818-based tricolour LED in the form of an Adafruit NeoPixel.

In the last-but-one *Cool Beans* column (*PE*, September 2020), we commenced a set of 'drip' experiments. We started by visualising the array as lying flat on the floor with individual drips of virtual water falling onto it from above. Each drip lit its associated pixel (ping pong ball) with white light.

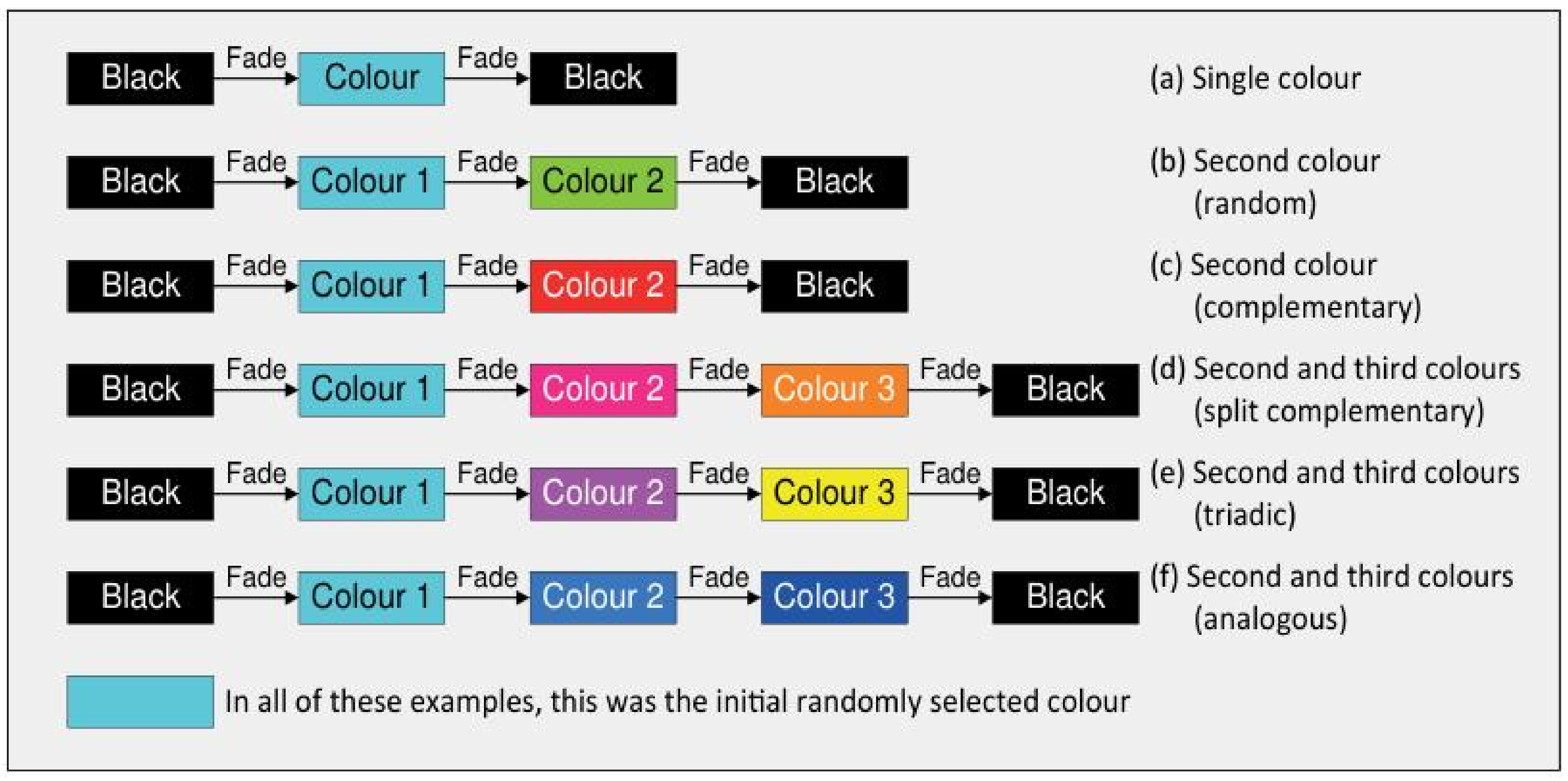
The way we implemented our original algorithm, each drip appeared in a random location, turned hard on, and then turned hard off again. The duration of each drip was random, as was the inter-drip delay (ie, the delay between adjacent drips). Next, we decided to light our drips with random colours, which we selected from a palette comprising three primary colours (red green and blue), three secondary colours (yellow, cyan, and magenta), and six tertiary colours (flush orange, chartreuse, spring green, azure, electric indigo, and rose).

In my previous *Cool Beans* column, (*PE*, October 2020), we created some jolly useful functions that allow us to fade from one colour value to another. If you've only just started subscribing to *PE*, then you'll doubtless be delighted to discover that the back issues containing the aforementioned columns are available for purchase via the magazine's Digital Downloader page (**https://bit.ly/3eC7hjS**).

More colour!

So, the current state of play is that each time a random virtual drip drops, as it were, we fade from black to a randomly selected colour, hold for a short time, and then fade back down again (Fig.1a). Hmmm. On the one hand, this isn't too shabby. On the other hand, are we the sort of men and women (and boys and girls) who can be satiated with a single saturated colour? 'No!' I cry, 'A thousand times no!'

As a first pass, let's pluck the low-hanging fruit and simply select a second colour at random. The idea is that we will fade from black to our first colour, then fade from our first colour to our second, then fade from our second back to black (Fig.1b). As usual, it would probably be a good idea if you were to download a copy of this sketch (program) in order to follow along with my cogitations and ruminations (file **CB-Nov20-01.txt** – it and the other files associated with this article, are available on the November 2020 page of the *PE* website).



Black
Fade
Colour
Fade
Black
(a) Single colour
Black
Fade
Colour 1
Fade
Colour 2
Fade
Black
(b) Second colour (random)
Black
Fade
Colour 1
Fade
Colour 2
Fade
Black
(c) Second colour (complementary)
Black
Fade
Colour 1
Fade
Colour 2
Fade
Colour 3
Fade
Black
(d) Second and third colours (split complementary)
Black
Fade
Colour 1
Fade
Colour 2
Fade
Colour 3
Fade
Black
(e) Second and third colours (triadic)
Black
Fade
Colour 1
Fade
Colour 2
Fade
Colour 3
Fade
Black
(f) Second and third colours (analogous)
In all of these examples, this was the initial randomly selected colour

Fig.1. Summary of the effects implemented by our current batch of ping-pong ball array sketches.

If you compare this program to our original single random colour version, you will see that the way we've built our code means the modifications are minimal. All these changes occur in our `DropDrip()` function. First, we randomly generate two drip colours rather than one:

```
// Get drip colors
iColor = random(0, NUM_WHEEL_COLORS);
dripColorOne = ColorWheel[iColor];

iColor = random(0, NUM_WHEEL_COLORS);
dripColorTwo = ColorWheel[iColor];
```

Later, after we've determined the values of any delays we wish to use, we add an extra call to our `CrossFade()` function as follows:

```
// Fade from black to first drip color, then hold
CrossFade(iNeo, COLOR_BLACK, dripColorOne,
FADE_UP_TIME, dripOnDelay);

// Fade from first drip color to second drip
color, then hold
CrossFade(iNeo, dripColorOne, dripColorTwo,
CROSSFADE_TIME, dripOnDelay);

// Fade from second drip color to black, then wait
CrossFade(iNeo, dripColorTwo, COLOR_BLACK,
FADE_DOWN_TIME, interDripDelay);
```

For your delectation and delight, I've created a video showing this latest incarnation of our drip sketch in action – you can see it at: **https://bit.ly/2G8i2ig**

Now, one problem with generating the second colour as a random value is that we could end up with the same colour as the first, which would be a tad boring. We could, of course, get around this by tweaking our code to ensure that the second colour is different to the first. Still and all, as they say, generating the second colour as a random value seems to lack a certain creative cunning and exhibits a scarcity of subtle sophistication. Perhaps we could adopt a more scientific approach.

Complementary combinations

In the visual arts, the term 'colour theory' refers to a body of practical guidance to colour mixing and the visual effects associated with specific colour combinations. For example, complementary colours are any two colours that

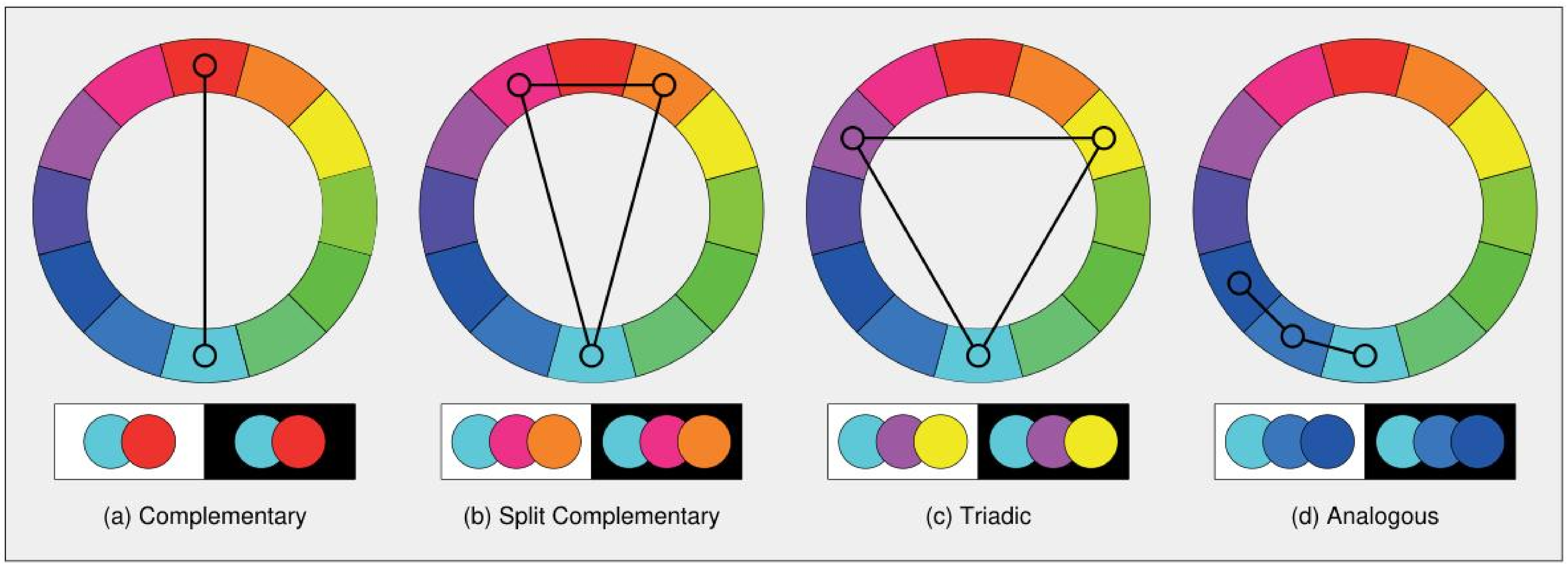

(a) Complementary (b) Split Complementary (c) Triadic (d) Analogous

Fig.2. Colour theory and colour combinations.

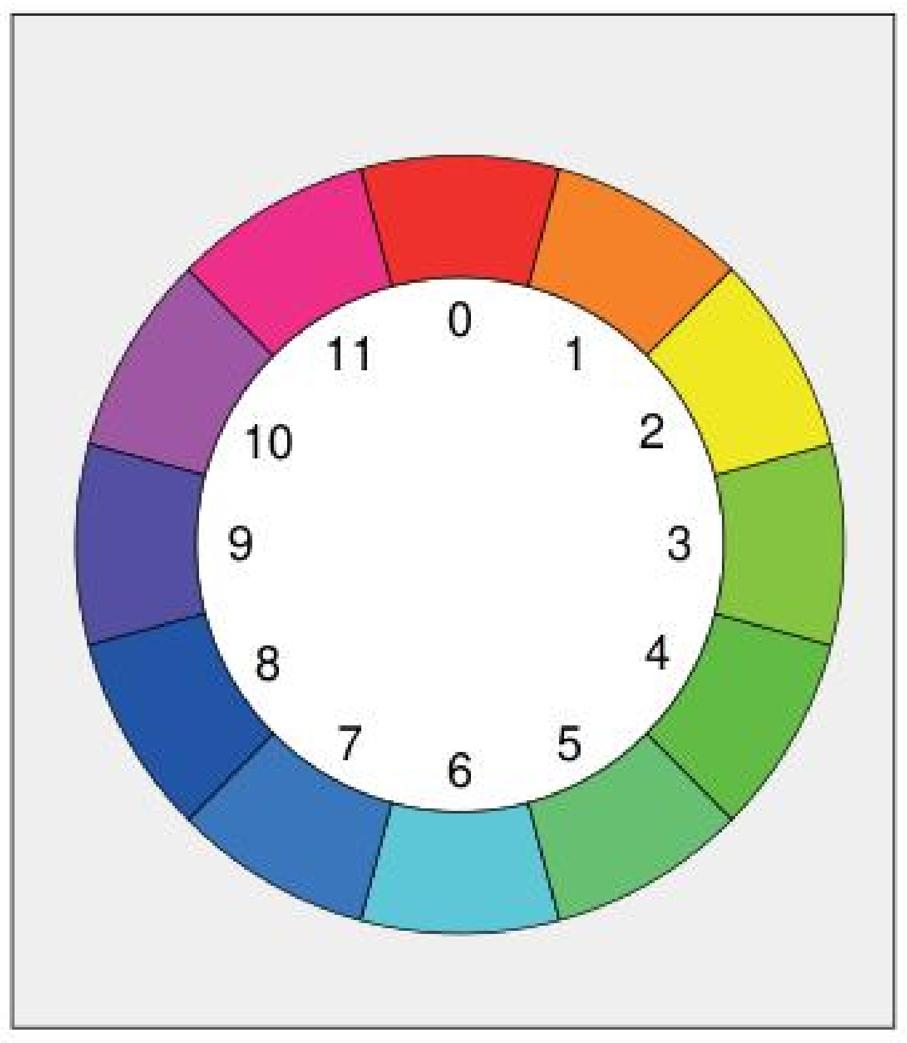


Fig.3. Index numbers used for colours.

are directly opposite each other on the colour wheel, thereby providing maximum contrast. In the traditional RYB colour model, examples of complementary colours would be red-green, yellow-purple, and blue-orange. Modern colour theory uses either the CMY subtractive colour model or the RGB additive colour model, in which case examples of complementary pairs are red-cyan, green-magenta, and blue-yellow (Fig.2a). The high contrast of complementary colours creates a lively look, but they can be jarring to the eye, so you might want to think twice before daubing every room in your house with complementary colour combinations.

The overall operation of our new sketch is depicted in Fig.1c, but how are we to determine the complementary counterpart to our initial randomly generated colour? Well, as you may recall, when we introduced the concept of the colour wheel in an earlier column (*PE*, September 2020), we annotated each of our colours with a number from 0 to 11 (Fig.3). These are the numbers we are using in our sketches to index (point to) the colours in our colour wheel.

I don't know about you, but I think this next bit is really rather clever (in this case, you can follow along by downloading file **CB-Nov20-02.txt**). In particular, take a look at the following lines of code from the `DropDrip()` function and compare these to their equivalents in our previous sketch shown earlier.

```
// Get drip colors
iColor = random(0, NUM_WHEEL_COLORS);
dripColorOne = ColorWheel[iColor];

iColorTmp = (iColor + (NUM_WHEEL_COLORS / 2)) %
NUM_WHEEL_COLORS;
dripColorTwo = ColorWheel[iColorTmp];
```

Observe that we generate the first colour as a random value as before. Since we know our colour wheel contains 12 colours (we defined this in our sketch as `NUM_WHEEL_COLORS`), we therefore understand that we need to add half this value (ie, 6) to the index value of our first colour to generate the index value of its complement, which will be our second colour.

In the case of our current sketches, we could, of course, simply use `(iColor + 6)` for this portion of our algorithm. The reason we used `(iColor + (NUM_WHEEL_COLORS / 2))` is to 'future proof' our code in case we were to decide to increase the size of our colour wheel at some stage in the future. (Yes, I know, a pretty cunning move.)

Now, the `(iColor + (NUM_WHEEL_COLORS / 2))` portion of the calculation would work 'as is' so long as the index value of the first colour was between 0 and 5, because this would result in an index value for the second colour between 6 and 11. But what happens if the index value of the first colour is between 6 and 11? In this case, we would end up with an index value for the second colour between 12 and 17. Since our colour wheel contains only 12 colours indexed from 0 to 11, this would be problematic, to say the least. The solution is to use the `%` (modulo) operator, which returns the integer remainder from an integer division. This explains the `% NUM_WHEEL_COLORS` (which equates to `% 12`) portion of our algorithm, which ensures we only ever end up with index values between 0 and 11 for our second colour.

Once again, I've created an eye-catching video showing this complementary colour incarnation of our drip sketch in action (**https://bit.ly/3lzUDqa**).

A cornucopia of colour combinations

Now we are really going to up our game because we are going to move to using three colours for each drip. We'll start with a split complementary implementation as illustrated in Fig.1d and Fig.2b. As we see, this is a variation of the original complementary scheme. In this case, in addition to the base colour, we use the two colours either side of the base colour's complement.

Let's start by considering how we are going to generate our three colours. As we see below, we commence by generating the first colour as a random value as before, and then we generate our split complementary values by tweaking the algorithm we used to generate our complementary value (you can follow along by downloading file **CB-Nov20-03.txt**).

```
// Get drip colors
iColor = random(0, NUM_WHEEL_COLORS);
dripColorOne = ColorWheel[iColor];

iColorTmp = (iColor + (NUM_WHEEL_COLORS / 2) -
1) % NUM_WHEEL_COLORS;
dripColorTwo = ColorWheel[iColorTmp];

iColorTmp = (iColor + (NUM_WHEEL_COLORS / 2) +
1) % NUM_WHEEL_COLORS;
dripColorThree = ColorWheel[iColorTmp];
```

The next part is where we fade from colour to colour, which simply requires us to add one more call to our `CrossFade()` function as illustrated below:

```
// Fade from black to first drip color, then hold
CrossFade(iNeo, COLOR_BLACK, dripColorOne,
FADE_UP_TIME, dripOnDelay);

// Fade from first drip color to second drip
color, then hold
CrossFade(iNeo, dripColorOne, dripColorTwo,
CROSSFADE_TIME, dripOnDelay);

// Fade from second drip color to third drip
color, then hold
```

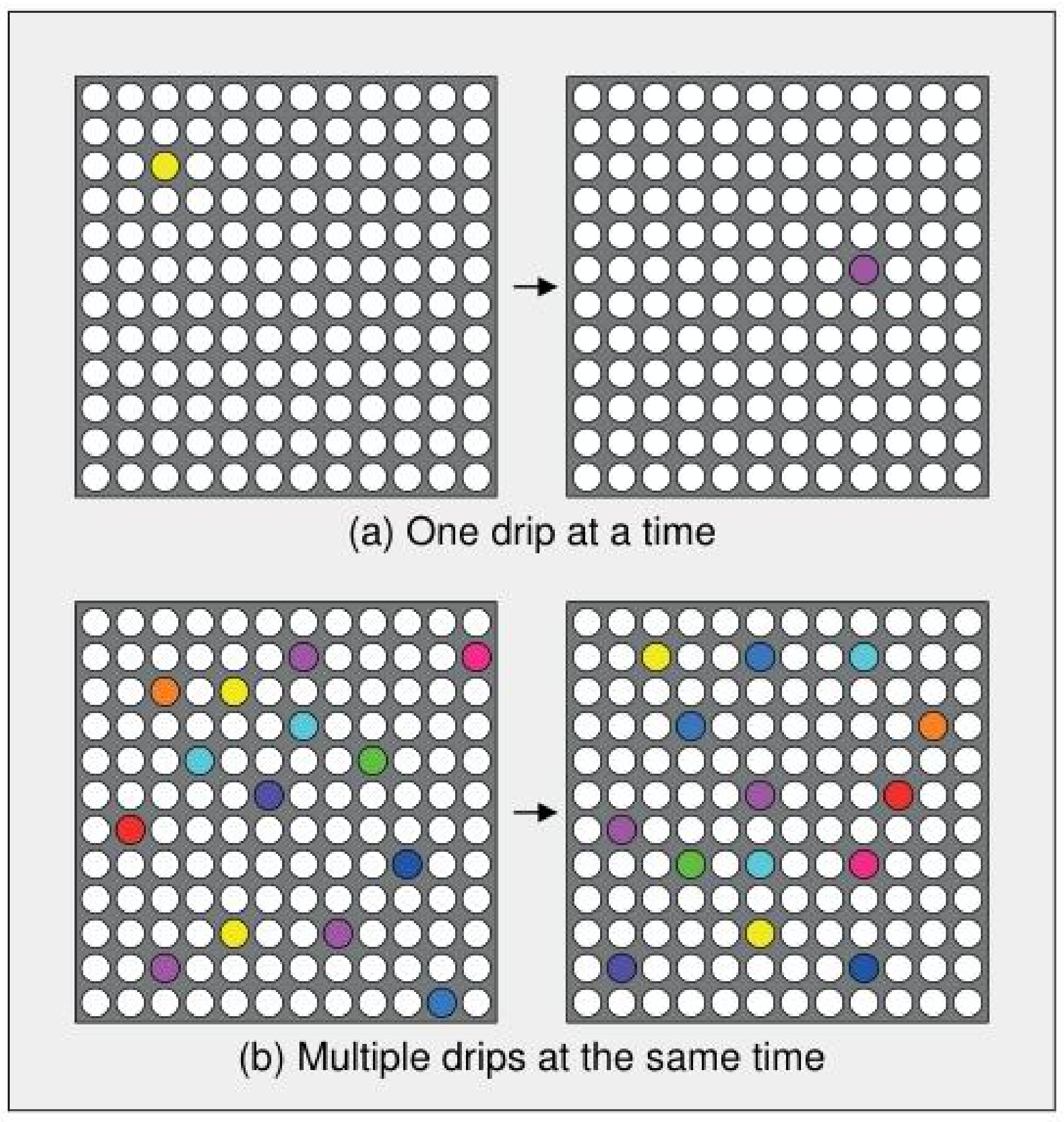


Fig.4. Single versus multiple drips.

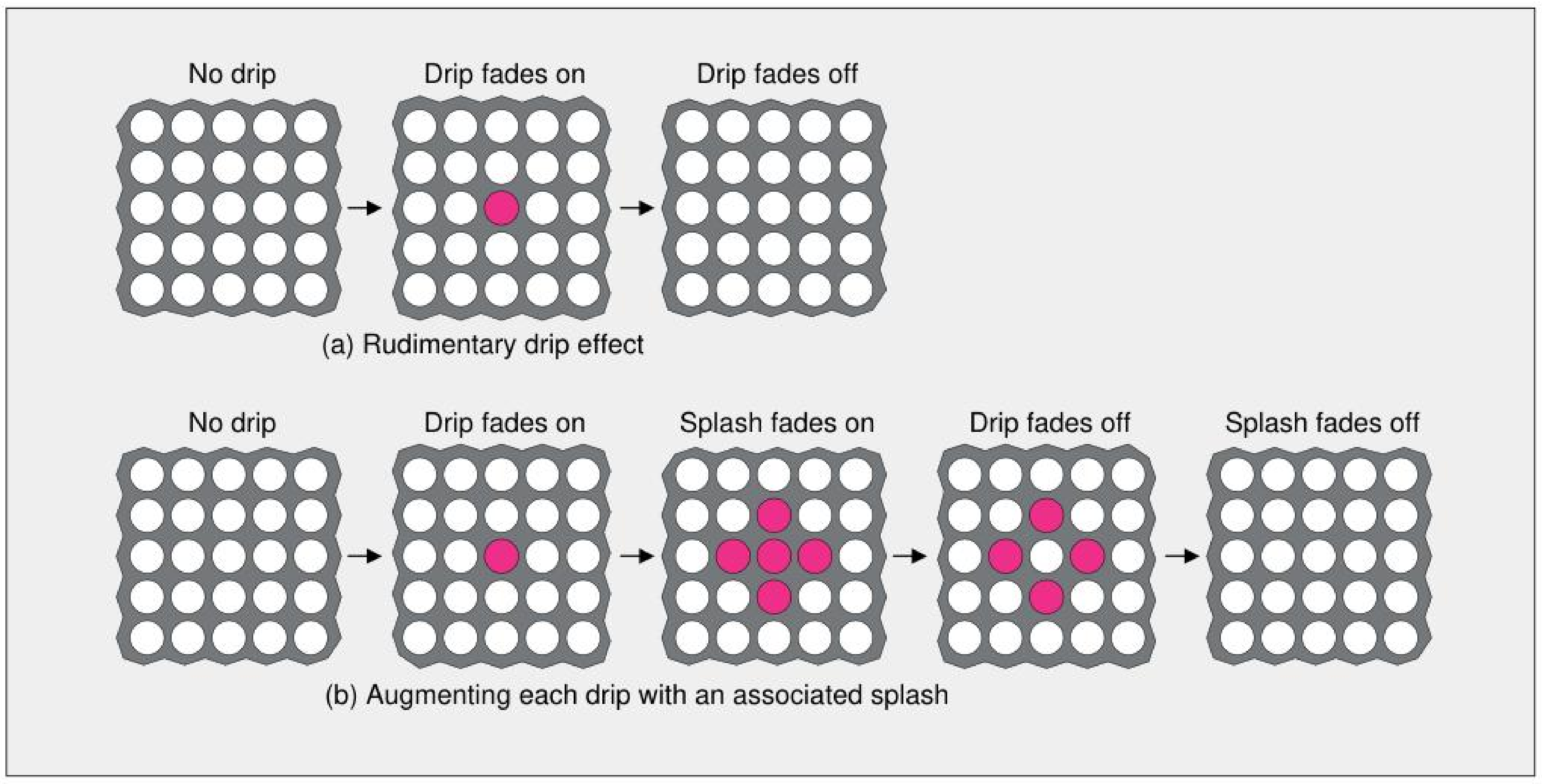


Fig.5. Basic drip effect compared to a 'drip plus splash' effect.

```
CrossFade(iNeo, dripColorTwo, dripColorThree,
CROSSFADE_TIME, dripOnDelay);

// Fade from third drip color to black, then wait
CrossFade(iNeo, dripColorThree, COLOR_BLACK,
FADE_DOWN_TIME, interDripDelay);
```

Just for giggles and grins, I also experimented with triadic colour combinations, as depicted in Fig.1e and Fig.2c; followed by analogous colour combinations, as depicted in Fig.1f and Fig.2d. Naturally, the code for these can be downloaded: files **CB-Nov20-04.txt** and **CB-Nov20-05.txt**, respectively. Furthermore, you can view videos of these split complementary, triadic, and analogous incarnations on my *Cool Beans* YouTube Channel (**https://bit.ly/3kBgdJD**).

As an aside, the reasons for our experiments with the various colour combinations discussed above goes far beyond our simple drip sketches. There are all sorts of fun things we might wish to display on our ping-pong ball array in the future. For example, I'm planning on implementing a version of *Conway's Game of Life* (**https://bit.ly/3fQdhqz**) – and knowing how these colour combinations work may well prove to be invaluable to those efforts.

We demand more drips!

I think it's fair to say that everything we've done thus far has been pretty exciting, but we could do better. Until now, for example, we've implemented only a single virtual drip at a time (Fig.4a). Suppose we decide to allow multiple drips to occur at the same time (Fig.4b)?

Obviously, we could simply pick a random group of pixels and fade them all on and all off at the same time, and then repeat this action with another random group of pixels, but where would the fun be in that? Apart from anything else, this approach would fall far short of representing randomly occurring drips. What we want is to allow multiple drips to be active at the same time, but for their start and end times to be randomly determined such that they overlap in interesting and unpredictable ways.

We might even decide to augment our drips with a 'splash' (or 'puddle') effect. For example, neglecting the colour-to-colour fades we discussed earlier, the way in which our current drips work is that they essentially fade on and then fade off again (Fig.5a).

By comparison, suppose that, following the initial drip, our virtual water droplet splashes out into the pixels north, south, east, and west of our original pixel. There are all sorts of things we could play with here, such as having the fading up of the splash pixels overlap the fading down of the initial drip pixel. We might also decide to experiment with making the colour of the splash pixels analogous to the colour of their parent drip pixel. I don't know about you, but I, for one, can't wait!

I'm sorry for the delay

Sad to say, the way in which we've been implementing things thus far will prove to be rather limiting. Consider the following interpretation of the main `loop()` function used in the Arduino's classic 'Blink' sketch. In this case, we are cycling around turning the LED on and off at a frequency of 1Hz (one cycle per second).

```
void loop()
{
   digitalWrite(PinLed, HIGH);
   delay(500);
   digitalWrite(PinLed, LOW);
   delay(500);
}
```

Observe the use of the `delay()` function. This is of a type known as a 'blocking function,' because it prevents (or blocks) anything else from happening while it meanders along through life twiddling its metaphorical thumbs.

When you come to think about it, all of our existing sketches have simply been enhanced versions of this Blink approach. Yes, we've implemented random drip lengths and random times between drips, but these have all been accomplished by means of the `delay()` function. And, yes, we've added fades, but these simply involved a series of incremental colour changes separated by calls to the `delay()` function.

The thing is, we've managed to 'get by' when playing with individual drips, but we would find it extremely difficult (if not impossible) to handle multiple simultaneous random drips using our current code architecture.

Next time…

I'll leave you for the moment to ponder how we might move to implement things like multiple drips and drips that splash. In my next column, we will 'Dump the Delay' and adopt a new way of creating our sketches that will allow us to realise all of these wondrous effects.

…but wait, there's more!

Hold onto your hats because this is 'hot off the press' as I pen these words. With regard to my *Tips and Tricks* columns, one of the most important suggestions I have if you wish to learn anything is to conceive a project you want to create or implement and then find out how to make it happen. In the case of learning a computer programming language, for example, while it's obviously a jolly good idea to read reference books on that language, working out how to code a real-world project is an extremely efficacious way to wrap one's brain around the nitty-gritty details.

The reason I mention this here is that my chum, Ted Fried, who is an FPGA designer at Apple, suggested that it would be a great idea to have a competition. Ted's proposal was that if you (yes *you*) were to create a program to run on my 12 × 12 ping pong ball array, you could email that program to me for me to run it on my array and post a video of it running on YouTube. Eventually, when we have enough videos, we could all vote to decide which programs provide the coolest and/or most interesting and/or most spectacular effects.

The only problem with Ted's idea is that you really need an array of your own to develop your program, which sort of defeats the object of the exercise. But turn that frown upside down into a smile because we've come up with a cunning plan (indeed, it is a plan 'as cunning as a fox what used to be Professor of Cunning at Oxford University,' as Edmund Blackadder once famously said).

In a nutshell, my chums at Alorium Technology (**https://bit.ly/30Za3MA**) have created a special simulator for us. This little beauty allows you to simulate your ping pong ball array program on your host computer. All you have to do is replace the `#include <Adafruit_NeoPixel.h>` statement with `#include <NeoPixel_Simulator.h>` – the rest of the program stays 'as-is' – pretty cool, eh?

Wnat to build your own amazing array? All the details are in previous *Cool Beans* columns, starting in March 2020.

Naturally, I've written a column explaining how all of this works in excruciating detail (**https://bit.ly/3h2mvkf**).

Also, for your delectation and delight, I've created a short video showing the same program running on the real array and on the simulator (you can view it here: **https://bit.ly/2E4ULgm**).

So, set to with gusto and abandon (and aplomb, of course). I cannot wait to see the cunning creations you come up with. Until then, have a good one!

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

Max's Cool Beans cunning coding tips and tricks

In an earlier Tips and Tricks column (PE, September 2020), we talked about how the integers we use in our sketches (programs) come in different sizes (8-, 16-, 32-, 64-bits) and flavors (signed and unsigned). In my previous *Tips and Tricks* column (*PE*, October 2020), we discussed the concept of casting; that is, explicitly promoting a smaller integer to a larger version, or demoting a larger integer to a smaller form.

As part of my *Cool Beans* column in that same issue, we introduced a function called `GetBlue()`, whose purpose was to accept a 32-bit unsigned integer as a parameter and return the least-significant 8 bits as follows:

```
uint8_t GetBlue (uint32_t tmpColor)
{
   return (uint8_t) (tmpColor & 0xFF);
}
```

We also noted the fact that, in this case, both the cast and the mask operations were unnecessary (the main reason for using them here is to make our intent clear to anyone who has to understand and maintain this program in the future), and that we could actually write this function as follows:

```
uint8_t GetBlue (uint32_t tmpColor)
{
   return tmpColor;
}
```

I made the comment: 'You may rest assured that the compiler's optimisation know-how should enable it to recognise any operations that are superfluous to requirements and remove them.' Well, if you ever find yourself wondering how your C/C++ code will be converted into assembly language on its way to machine code, there's a wonderful free tool called Compiler

Explorer you can use. For example, a comparison of the two versions of our function above shows that they return identical assembly code (**https://bit.ly/2P5GemJ**).

A cunning algorithm

I must admit that I'm quite proud of this one. In a *Tips and Tricks* column from long, long ago, relatively speaking (*PE*, May 2020), we were talking about the `for()` statement, which we noted could be abstracted as follows:

```
for (initialization; condition; modification)
{
   // More statements go here
}
```

'Initialisation' is where we initialise our control variable(s), 'condition' is where we perform a test, and 'modification' is where we increment or decrement our control variable(s). Note that the way I said this indicates the possibility of having multiple initialisation and modification variables. Generally speaking, beginners think of a `for()` statement as looking something like the following:

```
for (i = 0; i < 10; i++)
{
   // More statements go here
}
```

In reality, however, both the initialisation and modification sections can comprise multiple comma-separated elements looking something like the following:

```
for (i = 0, j = 10; i < 10; i++, j--)
{
   // More statements go here
}
```

Observe that we can only have a single condition, although this could have multiple parts, such as `( (i < 10) && (j > 0) )`, although this would be superfluous to requirements in this particular example.

The reason I'm waffling on about this here is that I just implemented a cunning algorithm using a `for()` loop of this ilk, and I thought it might be instructive to share it with you.

A rainbow of colours

I was starting to get worried with regard to my *Cool Beans* columns that you might think we were only ever going to light a single pixel at a time on our 12 × 12 array. Thus, I whipped up an interesting little sketch based on Adafruit's classic *Rainbow* algorithm. As a starting point, we present the dynamically changing rainbow using the 12 columns forming the array.

For each cycle, we first generate the 12 colours and store them in a 12-element array called `RainbowColors[]`, after which we call a function called `LoadRainbowColors()` to load these colours into the array. The key portion of this function is as follows:

```
for (int xInd = 0; xInd < NUM_COLS; xInd++)
{
   for (int yInd = 0; yInd < NUM_ROWS; yInd++)
   {
      iNeo = GetNeoNum(xInd, yInd);
      Neos.setPixelColor(iNeo, RainbowColors[xInd]);
   }
}
```

In this case we use two nested `for()` loops, each of which employs a single initialisation and modification variable. You can peruse the complete sketch if you wish (file **CB-Nov20-06.txt** – available on the November 2020 page of the PE website) and also watch a video of it in action on the array (**https://bit.ly/310Df5D**).

Next, I decided that I wished to present the rainbow on the array's diagonals. Let's think about this for a moment (maybe you could sketch things out on a piece of paper). If we had a 2 × 2 array, we would have three diagonals; a 3 × 3 array would give us five diagonals; a 4 × 4 array would have seven diagonals, and so on. The bottom line is that the number of diagonals in a square array is equal to the number of rows plus the number of columns minus one. Thus, in the case of our 12 × 12 array, we have 12 + 12 – 1 = 23 diagonals.

This means that, for each cycle, we now need to generate 23 colours and store them in a 23-element array called `RainbowColors[]`, after which we call a modified version of our `LoadRainbowColors()` function to load these colours into the array. The key portion of this modified function is as follows:

```
for (int  xInd = xStart, yInd = yStart;
          xInd <= xEnd; xInd++, yInd--)
{
   iNeo = GetNeoNum(xInd, yInd);
   Neos.setPixelColor(iNeo, RainbowColors[iDiag]);
}
```

Observe that, in this case, we are using a single `for()` loop that employs two initialisation variables and two modification variables. Once again, you can ponder the complete sketch for this if you wish (file **CB-Nov20-07.txt**), and also watch a video of it in action (**https://bit.ly/2DXZsbZ**).

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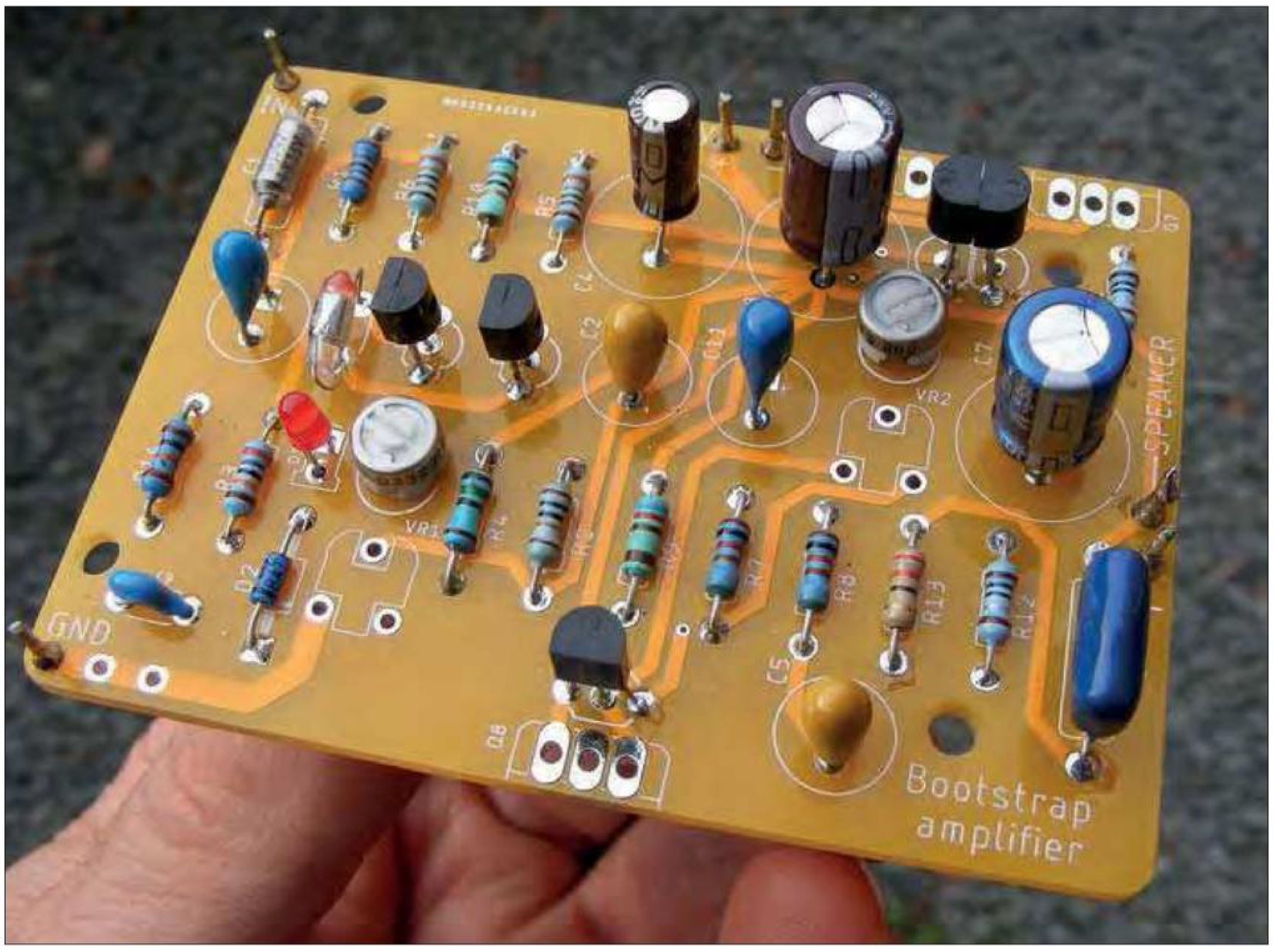
AUDIO OUT

By Jake Rothman

Theremin Audio Amplifier – Part 1



The *Bootstrap Amplifier* – an ideal partner for the PE Theremin.

This design was first presented as part of the *PE Theremin* project in August 2019. Back then, it was only a circuit diagram (Fig.34 p.54) and built on a prototyping board. Now that our PCB designer, Mike Grindle has done a board for it, it makes a useful project in its own right. It has a low total quiescent (idle) current of 3mA, which allows it to be used with a cheap PP3 9V zinc-carbon battery using a high-impedance 25Ω speaker (Fig.1). The amplifier is ideal for a portable theremin, radio and teaching, hence all the detail I'll be providing. It gives 275mW and the current consumption is 50mA on peaks of full volume.

Fig.1. For long battery life using a 9V PP3; a high impedance (25Ω) speaker is used.

Discrete design

Most of my commercial theremin designs have used the LM386, TB820 and LM384 power amplifier chips (Fig.2) for ease of production. They do have some disadvantages, however, mainly a high fixed quiescent current, resulting in shorter battery life. They also have excessive voltage gain and multiple input transistors, resulting in a significant hiss at minimum volume, which is a disadvantage when recording. The advantage of a discrete design (using individual transistors) is that every parameter can be optimised by hand. This approach is rarely allowed into a commercial environment, but it's perfect for education, fun and for those with a little time on their hands.

Pesky presets

IC designers have the great advantage that all their transistors are on the same piece of silicon made in one go, giving inherent matching. They can also use as many transistors as they want for current sources, mirrors and bias circuits. This means few or even no adjustments are required. With most discrete circuits, the necessary adjustments are accomplished by preset resistors or 'Trimpots' (a trademark popularised by my favourite pot-maker, Bourns). Presets are a contentious point. There's no doubt that open 'skeleton' presets (shown in Fig.3) become unreliable as dirt and oxidation take their toll. *The Art of Electronics* says, 'don't use them, design your circuit properly'. A lecturer of mine in 1983, told me 'use circuit analysis, don't just put trimmers in'. Unfortunately, I've always loved 'knob-twiddling', getting that sweet-spot of tuning, minimum distortion or symmetrical clipping. For me, the art of electronic music technology has always

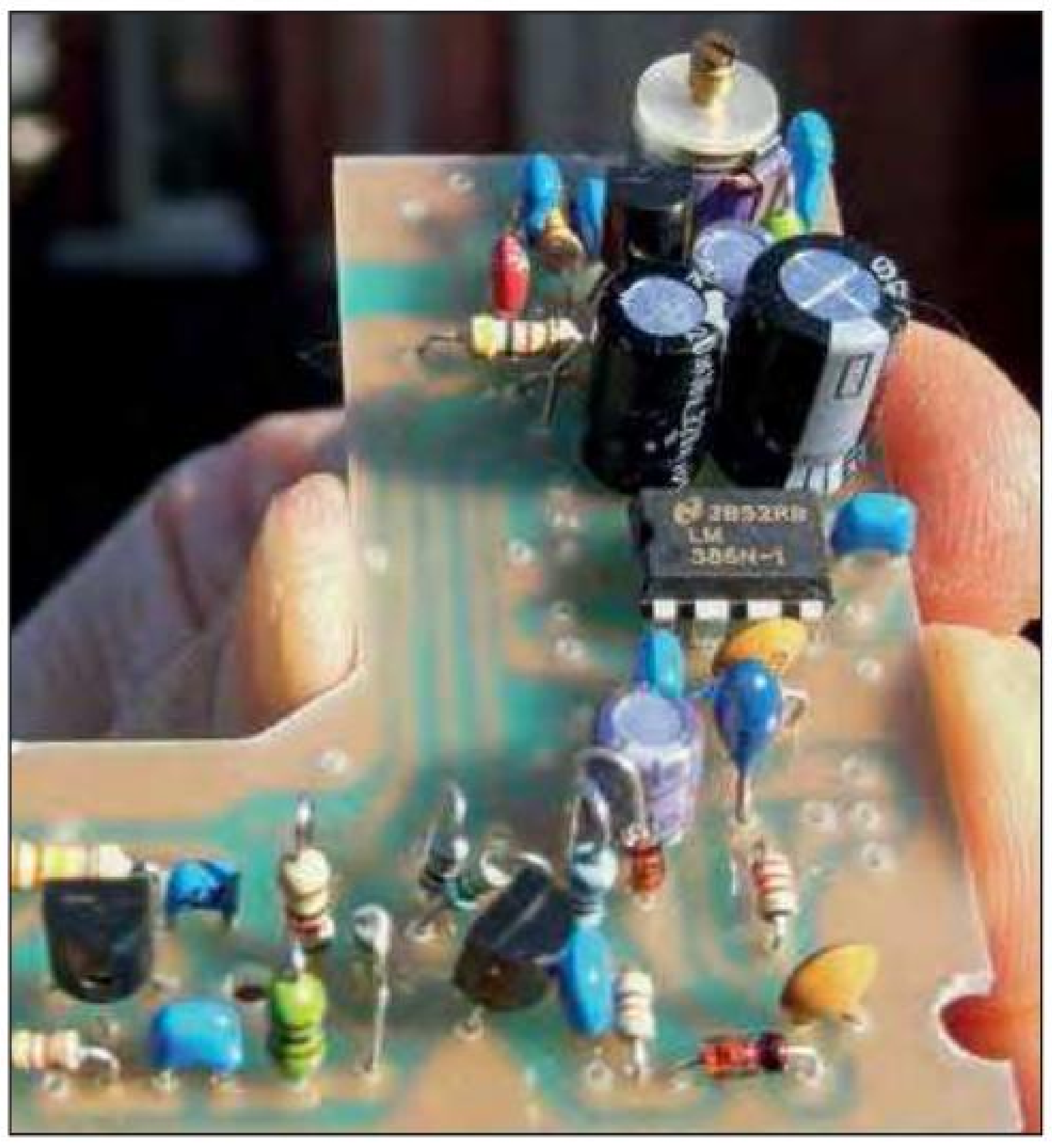


Fig.2. Small power amplifier chips such as this 8-pin DIL LM386 have long-replaced discrete designs in commercial electronics. However, everyone should make a small discrete circuit before being unleashed on expensive Hi-Fi designs. This is the classic National Semiconductor LM386, as used in my *Eclipse Theremin* (see: **http://theremin.co.uk**).

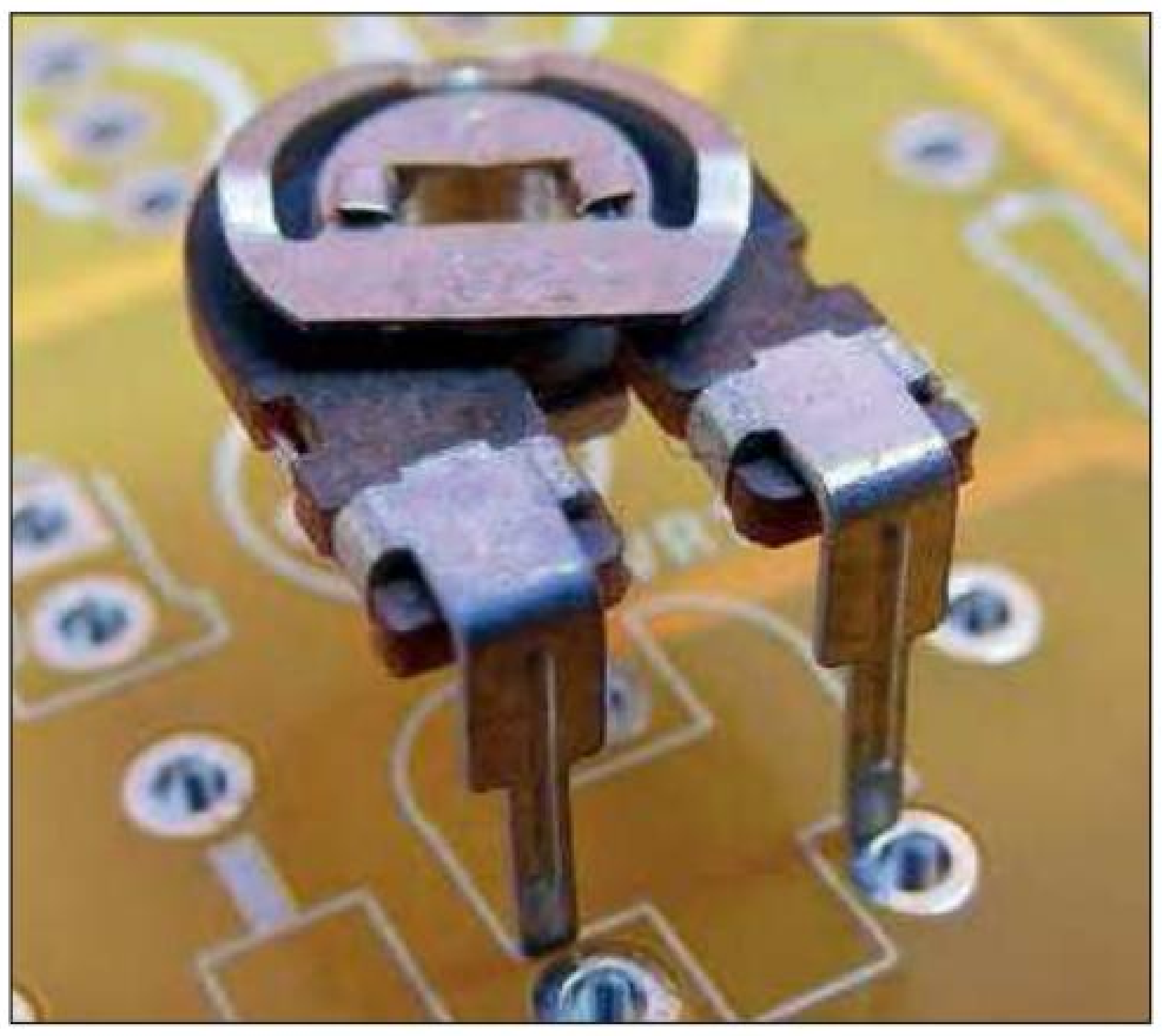


Fig.3. Open presets are a component to avoid if long term reliability is wanted. *The Art of Electronics* simply says, 'no'.

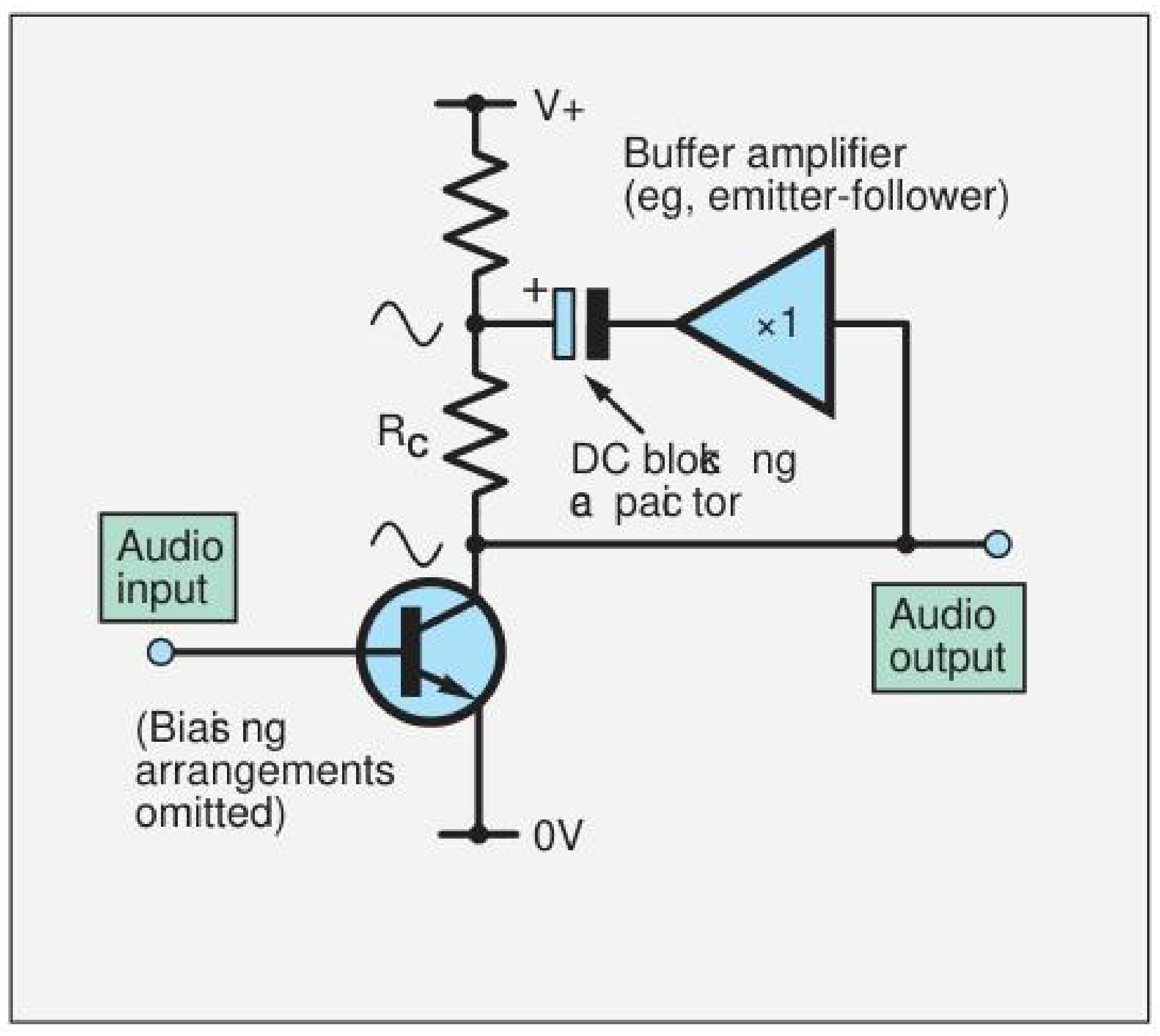


Fig.5. Bootstrapping employed on a common-emitter amplifier. This greatly increases voltage gain by making Rc appear much bigger than it is.

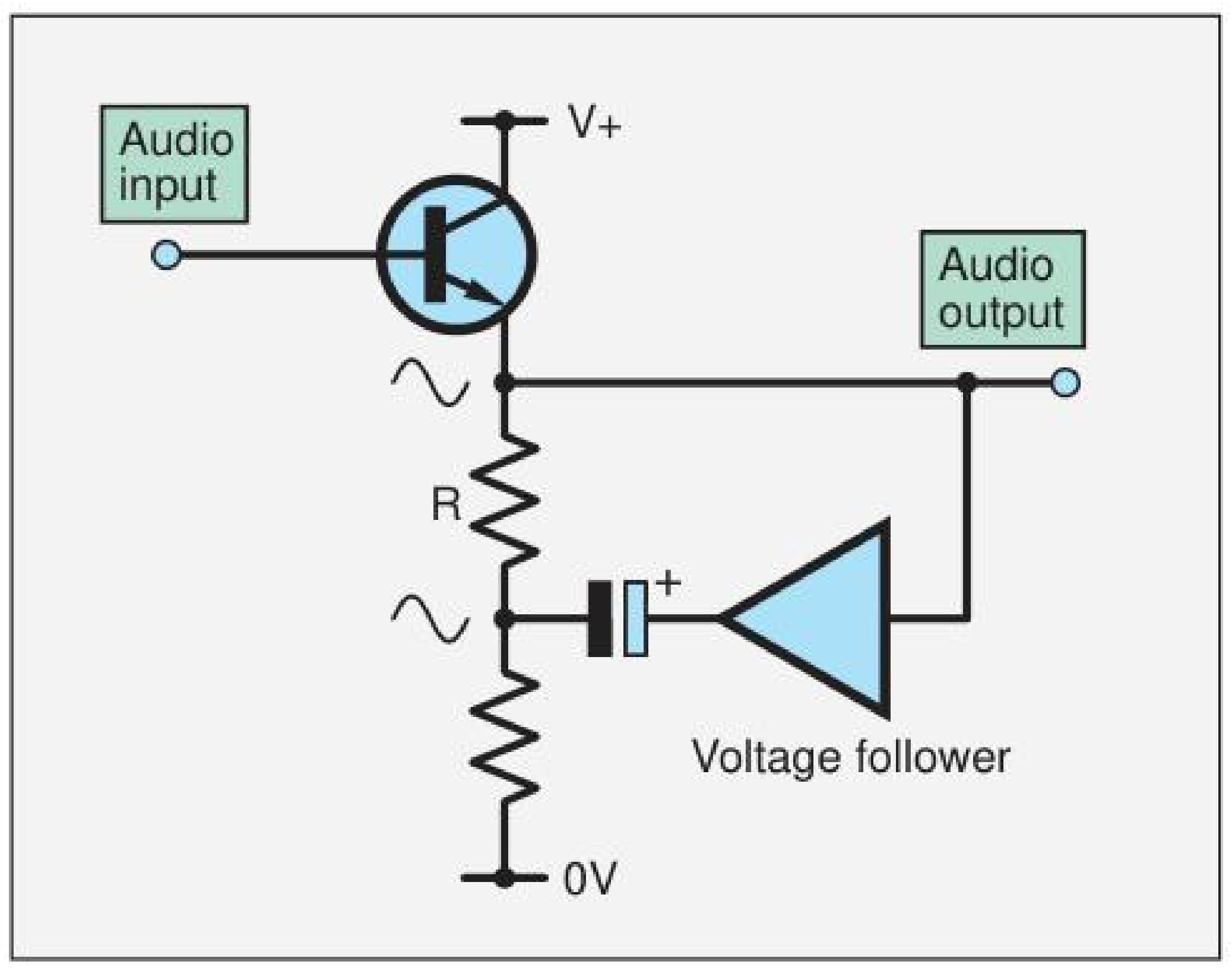


Fig.6. Bootstrapping an emitter-follower increases output by eliminating the loading effect of R. Multiple bootstraps can increase the output voltage swing in small power amplifiers by a couple of volts.

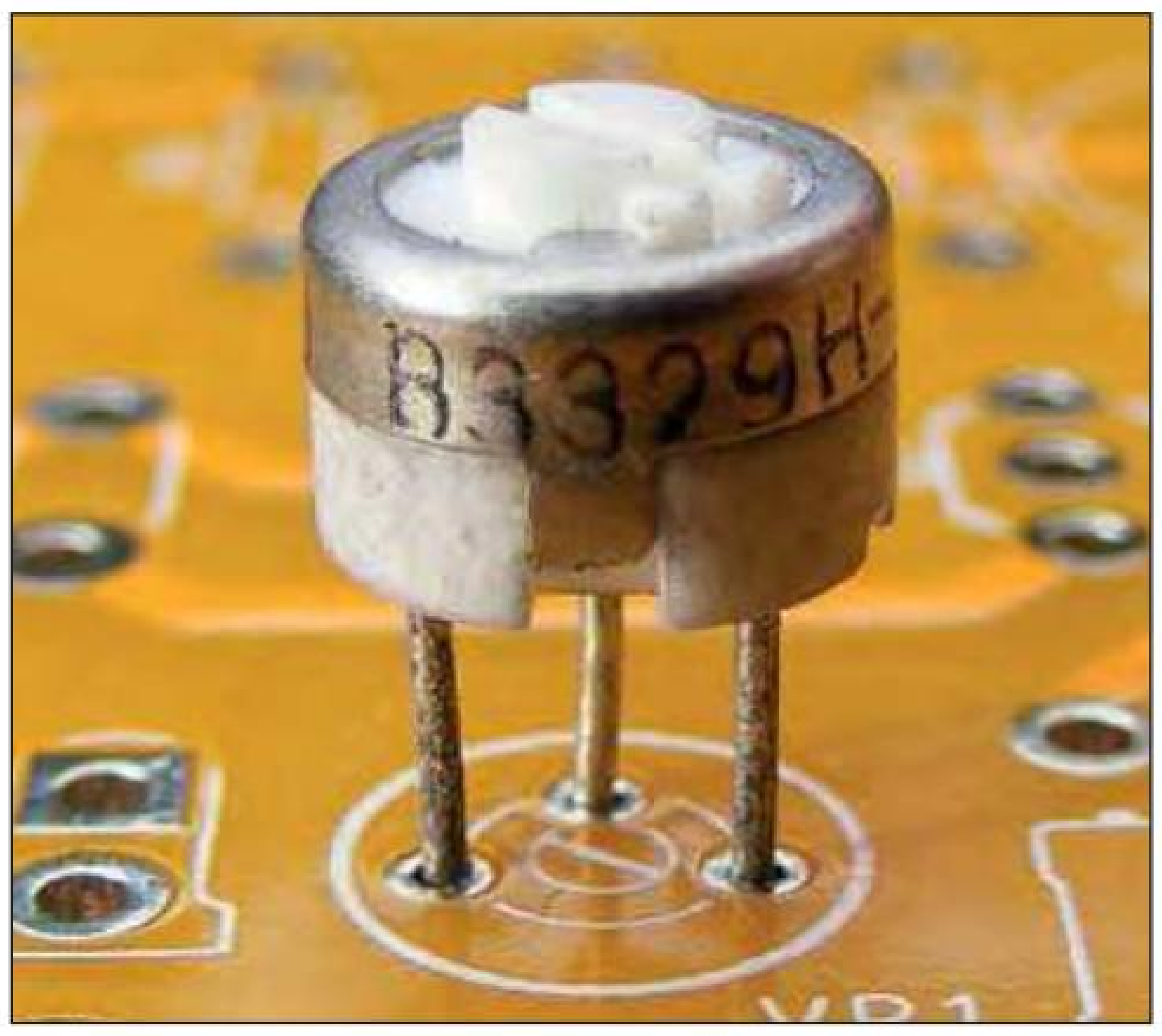


Fig.4. Bourns-style sealed presets are reliable, but can cost more than a power-amplifier chip.

been the feedback loop of human senses controlling electronic variables.

Apart from SMT devices and chips, component price inflation has now taken off. This is especially true where there has been a reduction in demand in analogue parts, for example JFETs or mechanical latching switches. Presets are no exception, the standard Bourns 3329H TO5 part, shown in Fig.4, has risen from around 20p to almost £1 since 2000. My 'new old stock' and the Chinese Suntan and Truohm copies from Rapid cover this problem. Note that there are two different physical outlines for different shapes of presets available on the board. Anyway, enough moaning, this circuit provides the experience of preset adjustments, which makes it worth it.

Bootstrapping, an old but useful trick

In the days when transistors were expensive and a lot of electronics ran on cheap low-power zinc-carbon batteries, bootstrapping was widely employed to get extra open-loop gain and voltage swing. This amp uses it in two locations and the PCB is labelled 'bootstrap amp', which was its working title during development. The name comes from the phrase 'pulling oneself up by one's bootstraps'. In electronic terms, this means pulling up the voltage of one end of a component (usually a resistor) while the other end is being driven in the same direction. The effect of this is to reduce the current through the resistor, making its apparent impedance much higher. The upper end has to be driven by a buffered voltage source, such as an emitter follower, since there has to be an additional energy source. A single transistor can't bootstrap itself. The technique applied to a common-emitter amp is shown in Fig.5. It can also be applied to an emitter follower as well, as shown in Fig.6. The impedance boost effect can also be provided by replacing the resistor with a current source, which is used in most chip amplifiers. However, bootstrapping provides an additional advantage, it increases the effective supply voltage, boosting the maximum output swing, which is very useful for battery-powered circuits. Conversely, current sources and sinks reduce the available output swing by around 1.5V, which is needed for its own operation (see Fig.7). A bootstrapped amplifier will give a few volts more than a current-source amplifier.

The disadvantage is that bootstraps generally have to be AC coupled with large-value capacitors, typically 1 to 220µF to get the voltage boosting effect. These capacitors operate in a way similar to the capacitors in a voltage-doubling circuit, where the capacitor's voltage is added to the supply voltage. Electrolytic capacitors have to be used, which are cheap, but they are large and dry-up over time. If solid-aluminium and tantalum capacitors are used, the cost is five times more.

Bootstrapping is out of favour in modern Hi-Fi amplifiers because the effect does not operate down to DC, giving an increase in distortion as the frequency decreases. Another problem is recovery from bursts of clipping, where the bias point can shift, although anyone who clips a Hi-Fi amp must be driving it too hard. Of course, it is possible to bootstrap a current source/sink to get both advantages. This was done in the TBA820 amplifier chip. Inductor loading is another way and is the most efficient of all, but audio inductors are expensive and difficult to obtain.

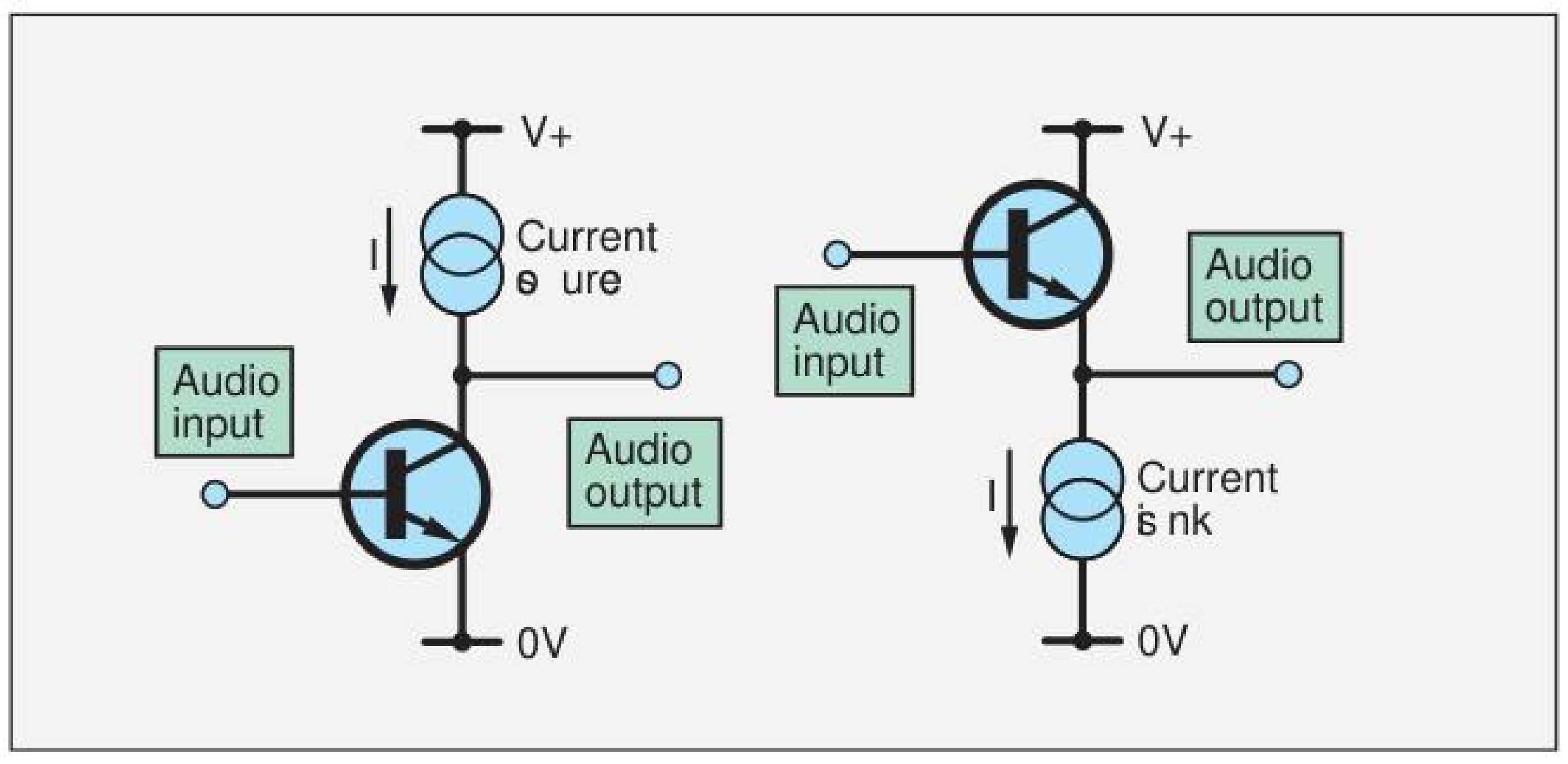


Fig.7. Current sources and sinks give the same gain and current boosting effect of bootstrapping, maintain the action down to DC and avoid the use of electrolytic capacitors. However, there is a voltage loss of 1 to 2V.

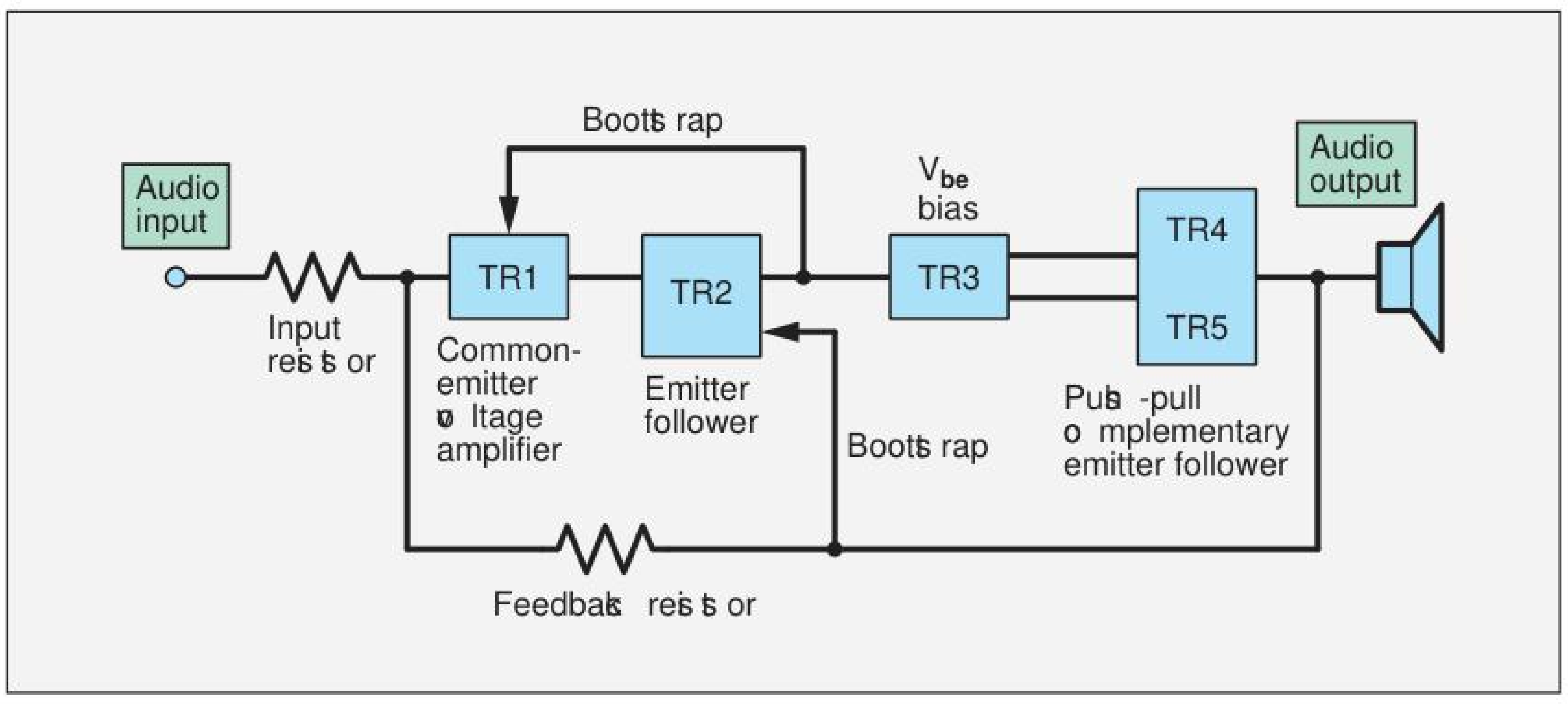


Fig.8. Block diagram of the *Bootstrap Amplifier*. Note the class-A emitter-follower TR2 driving the output stage and the bootstrap for TR1.

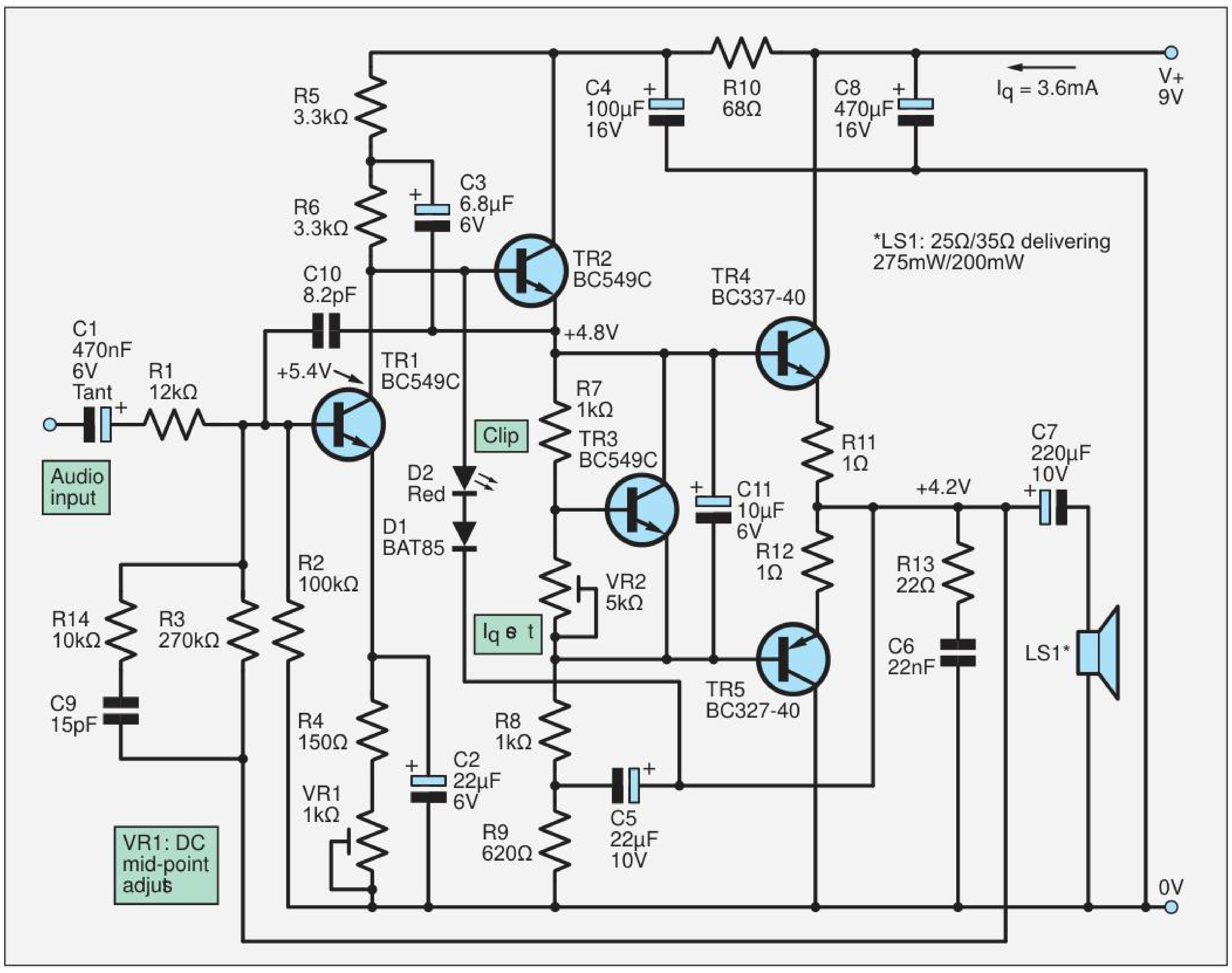

R5
3.3kΩ
C4
100µF
16V
R10
68Ω
C8
470µF
16V
Iq = 3.6mA
V+
9V
C3
6.8µF
6V
R6
3.3kΩ
TR2
BC549C
TR4
BC337-40
*LS1: 25Ω/35Ω delivering
275mW/200mW
C10
8.2pF
+4.8V
C1
470nF
6V
Tant
R1
12kΩ
+5.4V
TR1
BC549C
R7
1kΩ
Clip
TR3
BC549C
R11
1Ω
C7
220µF
10V
Audio input
D2
Red
C11
10µF
6V
+4.2V
D1
BAT85
R12
1Ω
R13
22Ω
R2
100kΩ
VR2
5kΩ
R14
10kΩ
R3
270kΩ
Iq set
C6
22nF
LS1*
C9
15pF
TR5
BC327-40
R4
150Ω
R8
1kΩ
C2
22µF
6V
VR1
1kΩ
R9
620Ω
C5
22µF
10V
VR1: DC mid-point adjust
0V

Fig.9. The full circuit of the *Bootstrap Amplifier*. Five transistors are about the minimum for a sonically acceptable performance with low current consumption.

Circuit design

The circuit follows a standard inverting power-amplifier pattern of input voltage amplifier stage (VAS) common-emitter stage (TR1) and push-pull emitter-follower output (TR4 and TR5), as shown in Fig.8. The difference is that an emitter-follower stage (TR2) is inserted between the voltage amplifier and output. This increases the drive current to the output stage and reduces the load on the VAS. This stage also provides bootstrapping drive to the VAS load resistor to increase the open-loop gain. A class-A follower is used because there is no point in using the output follower, as done in many designs, since it is class B. There would then be no bootstrap action around the crossover point, which is just where it is needed to reduce this nasty sounding distortion. To improve efficiency for battery operation, TR2's load resistor is bootstrapped by C5. TR3 is the usual V_{be}-multiplier stage to bias the output stage into class AB. Capacitors C6, C9 and C10 prevent high-frequency oscillations. The voltage gain is 22, half the normal minimum for IC amplifiers. The full circuit is shown in Fig.9.

Circuit overload

An overload indicator is provided which indicates when clipping occurs. LED1 turns on when the driver voltage at the collector of TR1 exceeds that of the output by 1.85V, which occurs at clipping. It can also provide a soft clip on the positive output cycle if the series Schottky diode D1 is shorted out. The rounded waveform top sounds nice, like a fuzzy guitar practice amp.

Next month

That's a nice overview of the *Bootstrap Amplifier* – next month, we'll build it.

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Teach-In 2017

Introducing the BBC micro:bit

PYTHON CODING ON THE BBC MICRO:BIT

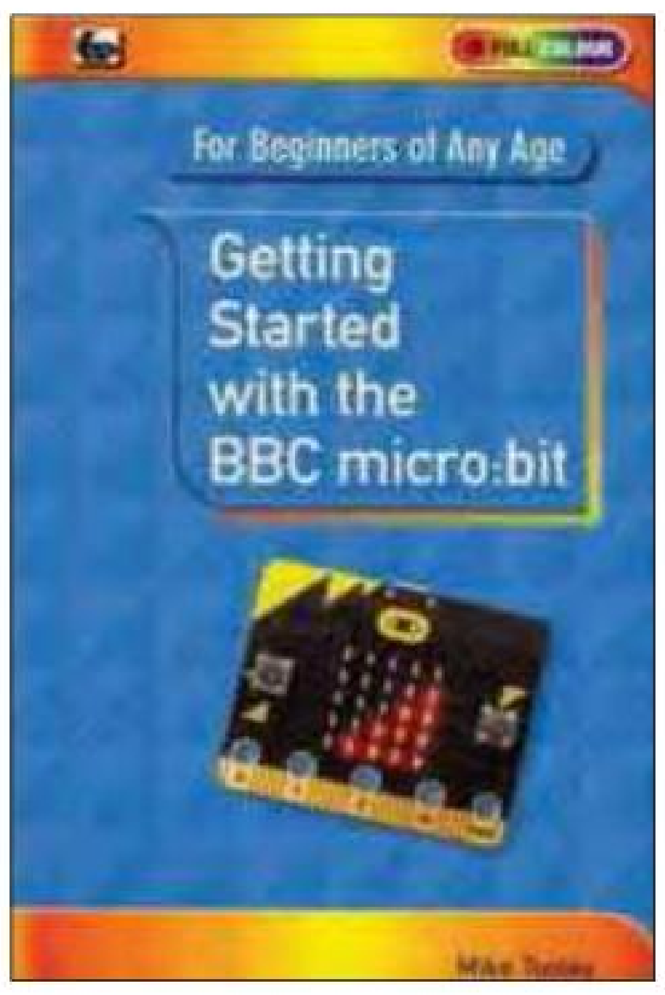
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** £7.99



GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages **Order code BBC MBIT** £7.99

THEORY AND REFERENCE

PRACTICAL ELECTRONICS HANDBOOK – 6th Ed
Ian Sinclair
440 pages **Order code NE21** £33.99

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Robert Penfold
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Owen Bishop
228 pages **Order code NE35** £36.99

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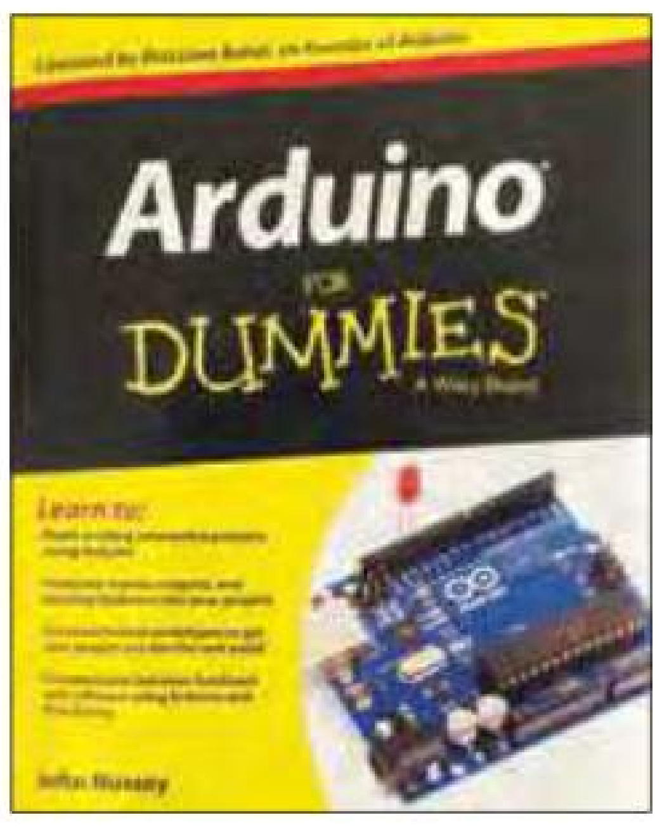
ARDUINO

COMPUTING AND ROBOTICS

Teach-In 2016

See opposite for our popular introduction to the Arduino



ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

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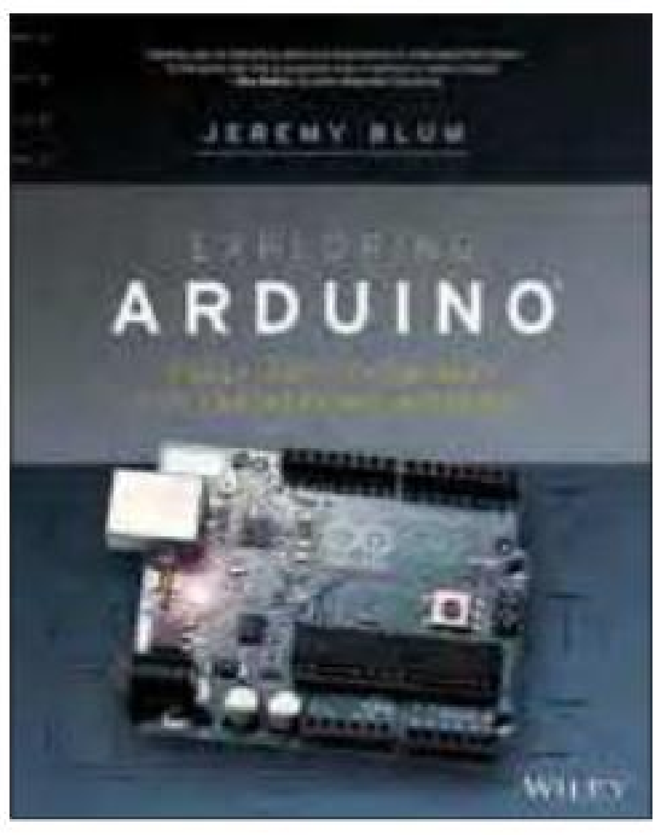

EXPLORING ARDUINO
Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction, this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

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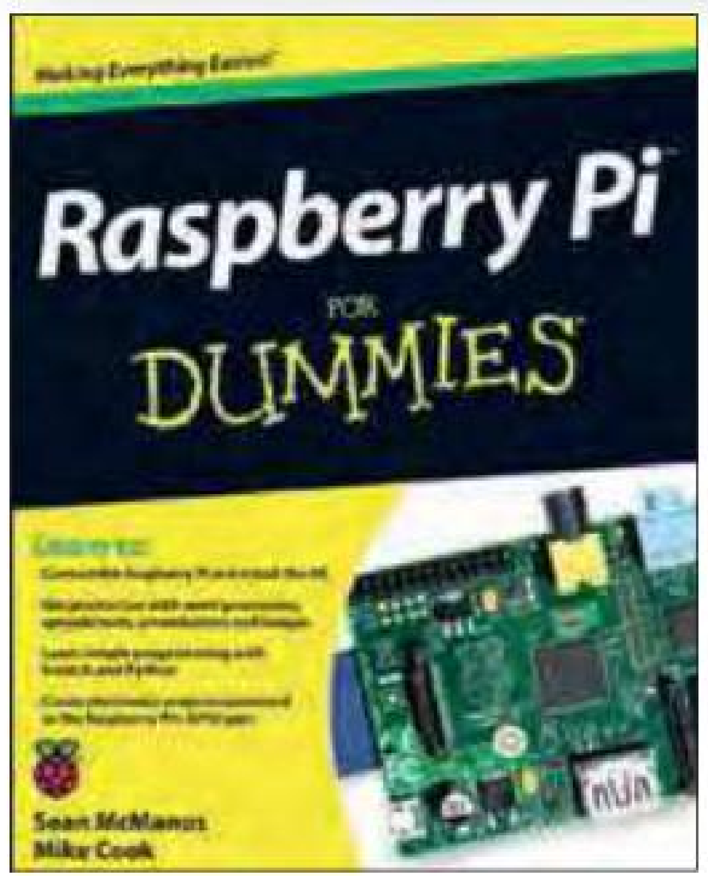

RASPBERRY Pi FOR DUMMIES
Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more!

Open this book and find:
What you can do with Python; Ways to use the Raspberry Pi as a productivity tool; How to surf the web and manage files; Secrets of Sonic Pi music programming; A guide to creating animations and arcade games; Fun electronic games you can build; How to build a 3D maze in Minecraft; How to play music and videos on your Raspberry Pi.

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TEACH-IN BOOKS

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ELECTRONICS TEACH-IN 6
A COMPREHENSIVE GUIDE TO RASPBERRY Pi

Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low-cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, and Home Baking.

The CD-ROM also contains all the necessary software for the series so that readers can get started quickly and easily with the projects and ideas covered.

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Mike & Richard Tooley

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Mike & Richard Tooley

Hardware – learn about components and circuits; Programming – powerful integrated development system; Microcontrollers – understand control operations; Communications – connect to PCs and other Arduinos

This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 will provide a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project.

This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

The CD-ROM includes files for Teach-In 8 plus Microchip MPLAB IDE XC8 8-bit Compiler and PICkit 3 User Guide. Also included is Lab-Nation Smartscope software.

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THE BASIC SOLDERING GUIDE

LEARN TO SOLDER SUCCESSFULLY!
ALAN WINSTANLEY

The No.1 resource for learning all the basic aspects of electronics soldering by hand.

With more than 80 high quality colour photographs, this book explains the correct choice of soldering irons, solder, fluxes and tools. The techniques of how to solder and desolder electronic components are then explained in a clear, friendly and non-technical fashion so you'll be soldering successfully in next to no time! The book also includes sections on reflow soldering and desoldering techniques, potential hazards, useful resources and a very useful troubleshooting guide.

Also ideal for those approaching electronics from other industries, the *Basic Soldering Guide Handbook* is the best resource of its type, and thanks to its excellent colour photography and crystal clear text, the art of soldering can now be learned by everyone!

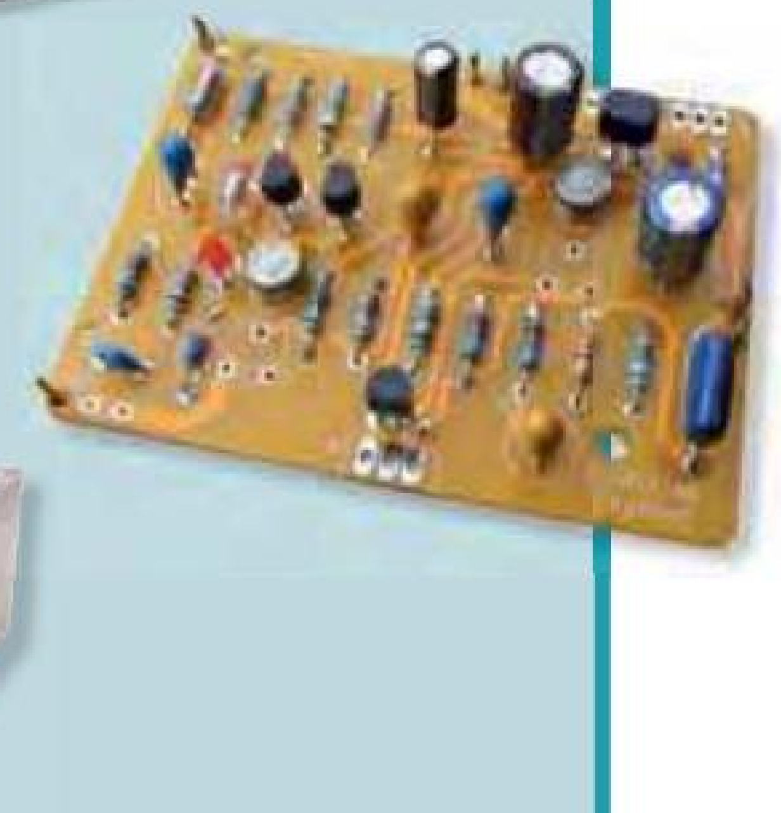
86 Pages **Order code AW1** **£9.99**

Next Month – in the December issue

LFSR Random Number Generator Using Logic ICs
By combining just a few logic ICs, it is possible to digitally generate a pseudo-random number sequence. This is an interesting circuit that will help you learn how logic ICs work. Why not use it to generate LED patterns to display on our *LED Christmas Tree* that we published this month?

Clever Controller for a Dumb Battery Charger
Most cheap battery chargers – the type you might buy at a hardware store or auto retailer – are pretty dumb. So dumb, they can actually destroy the battery under charge! If you have one of these chargers, you can upgrade it to one with a clever controller, suitable for flooded lead-acid, sealed lead acid (SLA) or even $LiFePO_4$ rechargeable batteries.

High Power – 45V/8A Variable Linear Supply – Part 3
We've described how our new *Linear Bench Supply* works and how to assemble its main PCB control module over the last two issues. Now it's time to finish it off: assemble it in the prepared case, attaching the front panel controls, wiring it up and doing the final calibration and testing.



Theremin Amplifier – Part 2
Next month, we conclude Jake Rothman's excellent 'Theremin amplifier'. Do note that if Theremins are not your thing this is still an excellent discrete component (no ICs) low-power circuit for general audio applications.

PLUS!
All your favourite regular columns from *Audio Out, Cool Beans and Circuit Surgery*, to *Make it with Micromite*, *Practically Speaking* and *Net Work*.

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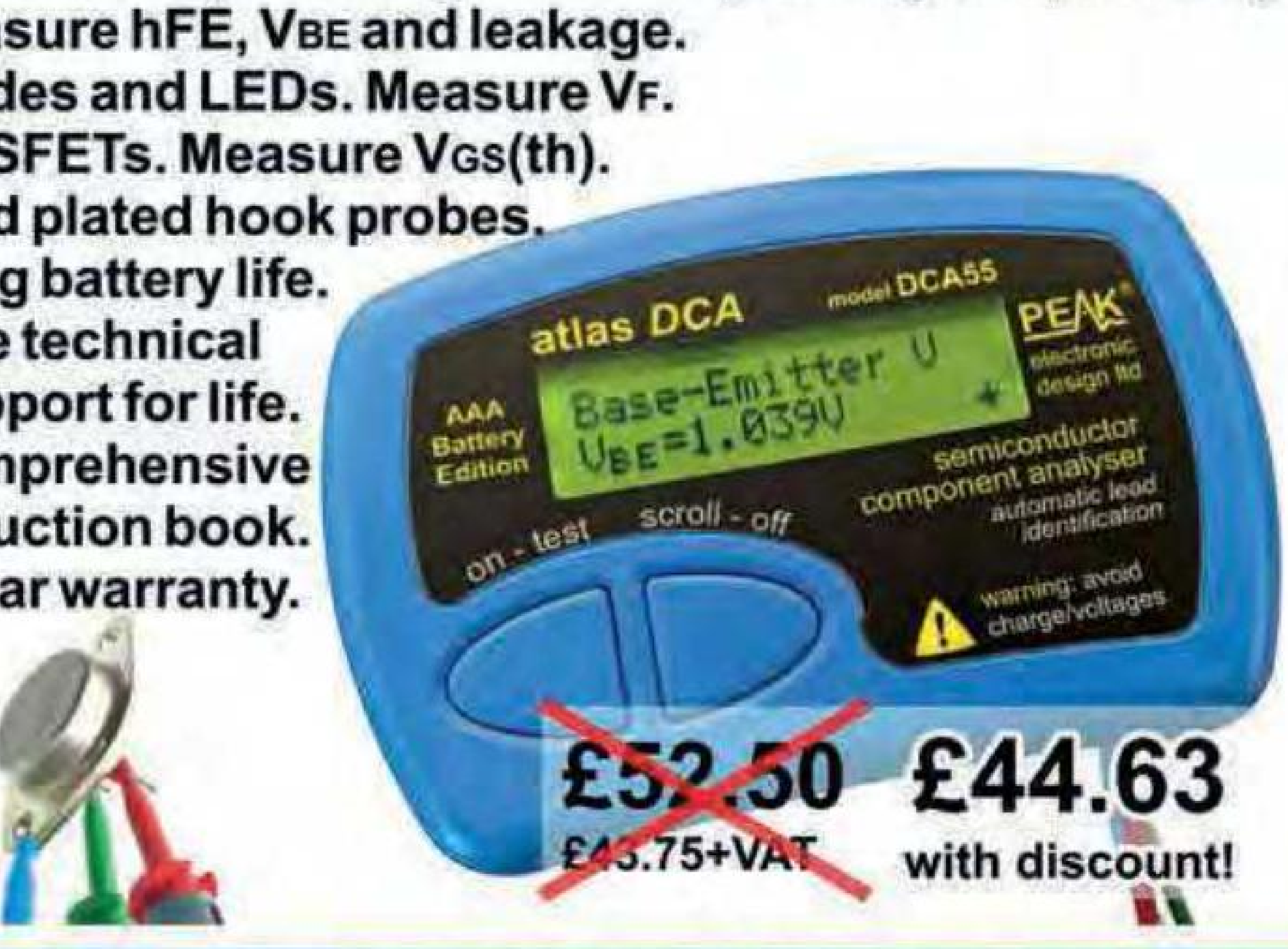
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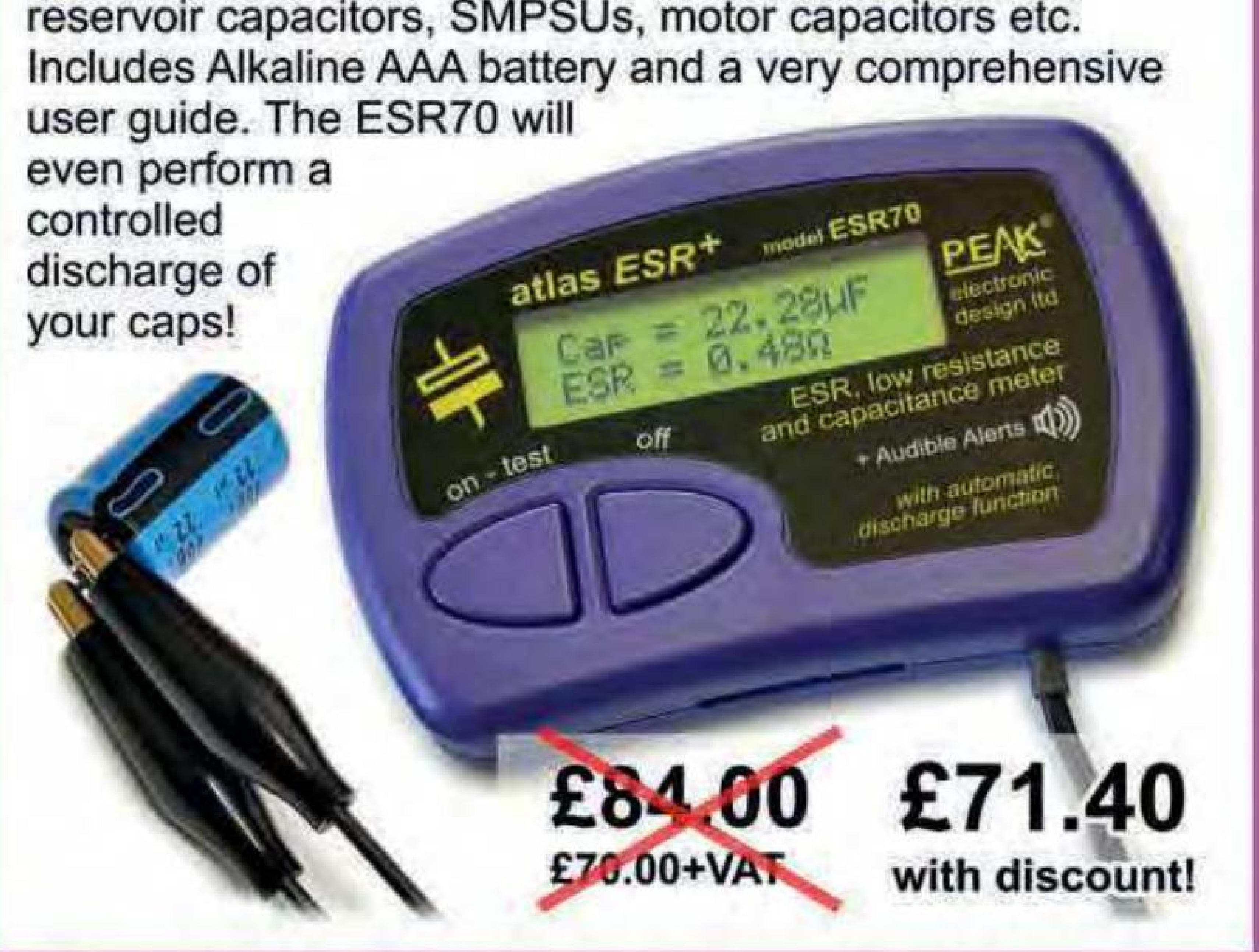
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